

# CHAPTER 6 – EARTHQUAKES AND GEOLOGIC HAZARDS: RISKS AND MITIGATION

## **CHAPTER CONTENT**

- 6.1 Earthquake Hazards, Vulnerability, and Risk Assessment**
  - 6.1.1 Identifying Earthquake Hazards
  - 6.1.2 Profiling Earthquake Hazards
  - 6.1.3 Assessment of State Earthquake Vulnerability and Potential Losses
  - 6.1.4 Assessment of Local Earthquake Vulnerability and Potential Losses
  - 6.1.5 Current Earthquake Hazard Mitigation Efforts
  - 6.1.6 Additional Earthquake Hazard Mitigation Opportunities
- 6.2 Landslide and Other Earth Movements Hazards, Vulnerability, and Risk Assessment**
  - 6.2.1 Identifying Landslide Hazards
  - 6.2.2 Profiling Landslide Hazards
  - 6.2.3 Assessment of Landslide Vulnerability and Potential Losses
  - 6.2.4 Current Landslide Hazard Mitigation Efforts
- 6.3 Volcano Hazards, Vulnerability, and Risk Assessment**
  - 6.3.1 Identifying and Profiling Volcano Hazards
  - 6.3.2 Assessment of Volcano Vulnerability and Potential Losses
  - 6.3.3 Current Volcano Hazard Mitigation Efforts
  - 6.3.4 Additional Volcano Hazard Mitigation Opportunities

## **About Chapter 6**

Chapter 6 assesses earthquake and geologic hazards. Earthquake is considered one of the three primary hazards, as explained in the State Hazard Mitigation Plan (SHMP) Chapter 1. This chapter discusses hazards from earthquakes; landslides and other earth movements, and volcanoes.

For more information on the criteria and template used for hazard risk assessments and a discussion of the hazard classification system, see [Chapter 1: Introduction, Section 1.2.3](#).

---

## **6.1 EARTHQUAKE HAZARDS, VULNERABILITY, AND RISK ASSESSMENT**

This section addresses earthquakes as one of three primary hazards noted in the classification system introduced in [Chapter 1: Introduction, Section, 1.2 Plan Overview](#). This risk analysis includes information identifying the following dimensions of this hazard:

- Overview of earthquake hazard
- Locations within the state (i.e., geographic areas) that are affected
- Previous occurrences within the state and the probability of future events (i.e., chances of recurrence)
- Seismic vulnerability and loss assessment efforts
- Current and future seismic mitigation efforts

### **6.1.1 IDENTIFYING EARTHQUAKE HAZARDS**

#### **Overview**

Earthquakes represent the most destructive source of hazards, risk, and vulnerability, both in terms of recent state history and the probability of future destruction of greater magnitudes than previously recorded.

Earthquakes are a significant concern for California for several reasons. First, California has a chronic and destructive earthquake history. Second, California has widespread earthquake vulnerability as indicated by California Geological Survey (CGS) mapping of potential earthquake shaking intensity zones, with these zones commonly located near populated areas. Third, nearly all local governments that have submitted Local Hazard Mitigation Plans (LHMPs) have identified earthquakes as a hazard of importance.

In addition to shaking, buildings are also vulnerable to ground displacements associated with primary fault rupture, liquefaction, differential settlement, and landslides. Inundations from tsunamis, seiches, and dam failures can also be major sources of loss to buildings and infrastructure.

### **Causes of Earthquakes: Plate Tectonics**

California is seismically active because it sits on the boundary between two of the earth's tectonic plates. Most of the state—everything east of the San Andreas Fault—is on the North American Plate. The cities of Monterey, Santa Barbara, Los Angeles, and San Diego are on the Pacific Plate, which is constantly moving northwest past the North American Plate. The relative rate of movement is about 2 inches (50 millimeters) per year. The San Andreas Fault is considered the boundary between the two plates, although some of the motion (also known as slip) is taken up on faults as far away as central Utah.

There are over 15,000 identified faults in California. Over 200 of these identified faults are considered very dangerous based on their slip rates in recent geological time (the last 10,000 years).<sup>96</sup> More than 70 percent of the state's 40 million people reside within 30 miles of a known fault where strong ground shaking could occur in the next 30 years.

The motion between the Pacific and North American Plates occurs primarily on the faults of the San Andreas system and the eastern California shear zone. Faults are more likely to have future earthquakes on them if they have more rapid rates of movement, have had recent earthquakes along them, experience greater total displacements, and are aligned so that movement can relieve the accumulating tectonic stresses. Nearly all movement between the two plates is on active faults.

The San Andreas Fault is not the only significant fault/plate boundary in California. The seismicity north of Cape Mendocino is controlled by faults associated with the Cascadia Subduction Zone, a large offshore fault system that separates the Juan de Fuca Plate to the west and the North American Plate to the east. This area is the most seismically active portion of the state. The Cascadia Subduction Zone is capable of producing great earthquakes (magnitudes greater than 8.0) and last ruptured in the year 1700, causing what was likely an earthquake in the Magnitude 9.0 range. The subduction zone is also capable of generating a large tsunami.

### **Earthquake Hazards: Shaking**

#### Overview

Damage due to ground shaking accounts for significant amount of all building losses in typical earthquakes. Building damage can be both structural and/or non-structural (i.e., damage to building contents) and both types of damage can cause injury or loss of life. More than 70 percent of the state's 40 million people reside within 30 miles of a known fault where strong ground shaking could occur in the next 30 years.

#### Amplification of Seismic Shaking

Although seismic waves radiate from their source like ripples on a pond, the radiation is not uniform due to the complex nature of an earthquake rupture, different paths the waves follow through the earth, and different rock and soil layers near the earth's surface. Large earthquakes begin to rupture at their hypocenter and the fault ruptures outward from that point. Because the speed of an earthquake rupture on a fault is similar to the speed of seismic waves, waves closer to the epicenter can be compounded by waves from farther along the rupture, creating

---

<sup>96</sup> Uniform Earthquake Rupture Forecast (UCERF 3 – 2014)

a pulse of very strong seismic waves that move along the fault in the direction of the fault rupture. Seismic waves may also be modified as they travel through the earth's crust. Shaking from the 1989 Loma Prieta Earthquake was concentrated to the north, toward San Francisco and Oakland, possibly due to the reflection of seismic waves off the base of the earth's crust.

As seismic waves approach the ground surface, they commonly enter areas of loose soils where the waves travel more slowly. As the waves slow down, their amplitude increases, resulting in larger waves with frequencies that are more likely to damage structures. Waves can also be trapped within soft sediments between the ground surface and deep, hard basement rocks, their destructive energy multiplying as they bounce back and forth producing much greater shaking at the ground surface. The CGS and the U.S. Geological Survey (USGS) recorded large ground waves at many locations during both the Loma Prieta Earthquake and the 1994 Northridge Earthquake. Topography can also affect the local intensity of earthquake shaking. Topographic highs, such as hills and ridges, enhance shaking and topographic lows, such as valleys, lessen shaking. This phenomenon has been observed in many earthquakes, and "topographic amplification" was quite pronounced in the 2003 San Simeon Earthquake where most of the shaking damage to residential structures occurred at the tops of hills.

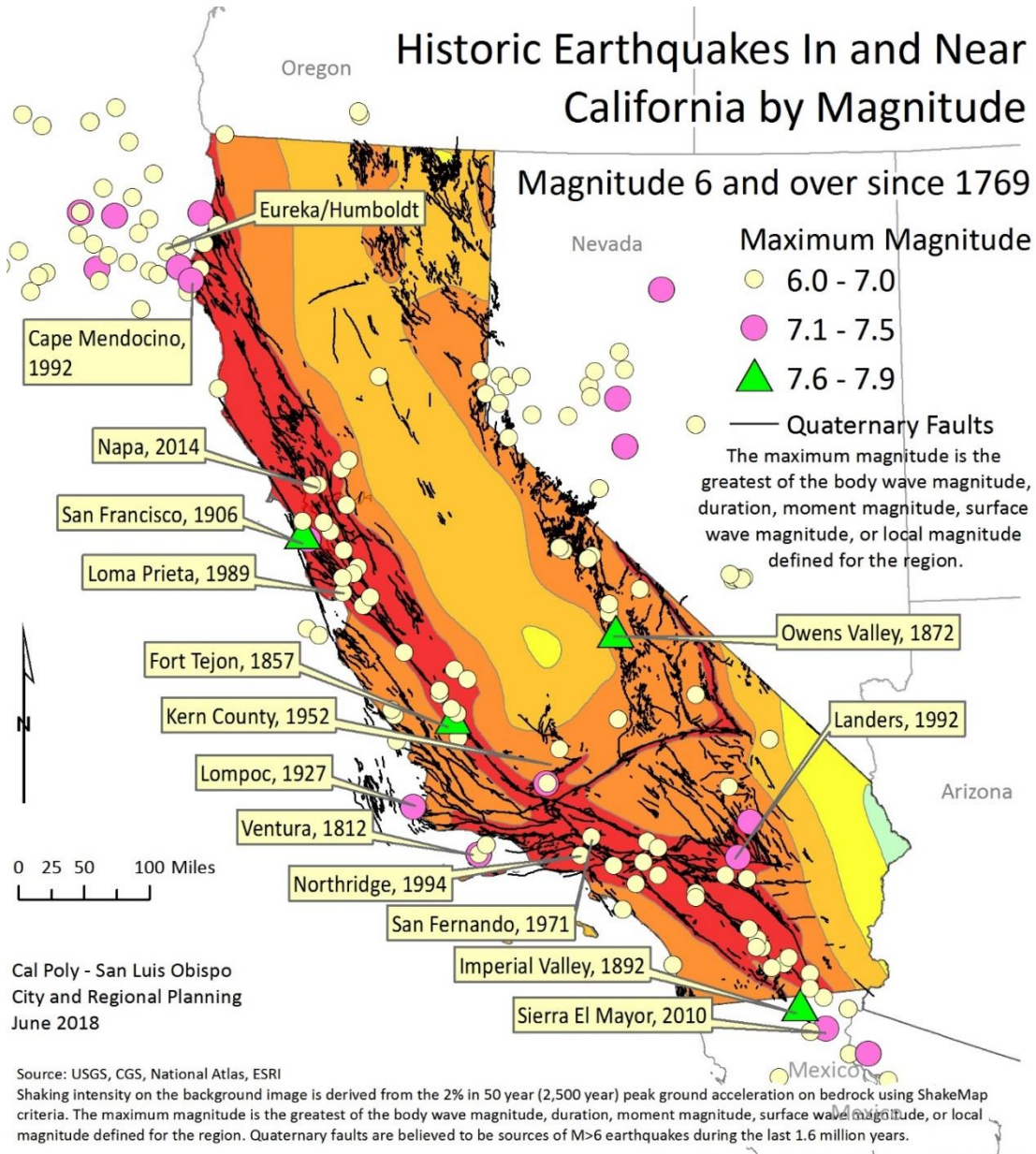
#### Loma Prieta Earthquake Damage, San Francisco, 1989



Source: U.S. Geological Survey

Unexpectedly large seismic ground waves and their resulting damage may be produced from a relatively distant earthquake. Shaking from the 1999 Hector Mine Earthquake in the Mojave Desert produced seismic waves with amplitudes of up to 15 centimeters in the Los Angeles basin, more than 200 kilometers from the epicenter. While there was little damage from the Hector Mine Earthquake, other large earthquakes have caused damage in distant places. For example, Nevada's 1954 Dixie Valley Earthquake resulted in damage to critical facilities in Sacramento due to water sloshing.

Map 6.A: Historic Earthquakes In and Near California by Magnitude (1769-2017)



MMI	Damage	Effects
X	Very Heavy	Some well-built, wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
IX	Heavy	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
VIII	Moderate to Heavy	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
VII	Moderate	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly-built or badly designed structures; some chimneys broken.
VI	Light	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
V	Very Light	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.

Map 6.A shows the pattern and selected dates of earthquakes in and near California during the past 240 years.

## Earthquake Hazards: Ground Failure

Fissuring, settlement, and permanent horizontal and vertical shifting of the ground often accompany large earthquakes. Although not as pervasive or as costly as the shaking itself, these ground failures can significantly increase damage and under certain circumstances can be the dominant cause of damage. Studies after the 1994 Northridge Earthquake showed that when ground failure was involved, damage to residential dwellings was three to four times greater than average shake damage. Because of their geographic extent, networked infrastructures such as water, power, communication, and transportation lines are particularly vulnerable to ground failures.

### Fault Rupture

The sudden sliding of one part of the earth's crust past another releases the vast store of elastic energy in the rocks as an earthquake. The resulting fracture is known as a fault, while the sliding movement of earth on either side of a fault is called fault rupture. Not only is the fault rupture responsible for causing the earthquake and the resulting shaking, when that rupture extends to the earth's surface the displacement can catastrophically damage any structures or utility lines that lie on top or cross it.

### Liquefaction

In addition to the primary fault rupture that occurs right along a fault during an earthquake, the ground many miles away can also fail during intense shaking. One common type of failure is liquefaction, which occurs when loose, water-saturated sand is shaken by the earthquake and turns into a fluid-like substance, essentially a "quicksand," causing it to lose the ability to support buildings and other structures. Areas susceptible to liquefaction include places where sandy sediments have been deposited by rivers along their course or by wave action along beaches.

Ground deformation from liquefaction is caused by settlement and/or lateral spreading. Settlement can cause damage when the amount settlement varies significantly across the length of a structure. Lateral spreading occurs when liquefaction occurs on gently sloping ground and the liquefied material at depth allows the area to slide, often toward a vertical discontinuity or "free face" such as a creek or stream channel. Liquefaction can occur in susceptible soils below bodies of water, and settlement and lateral spreading can damage structures built on or adjacent to these areas. Transportation bridges across water bodies, wharves, piers and other structures at ports and harbors, and underwater utility lines can be severely damaged by this hidden hazard.

### Landslides

Landslides are the result of the down-slope movement of unstable hillside materials under the influence of gravity. Sudden failure can be triggered by earthquake shaking, excavation of weak slopes, and heavy rainfall, among other factors. Landslides caused by earthquakes can be widespread over the area of highest shaking intensity and also at greater distances if hillsides are in a susceptible condition. Earthquake landslides can significantly damage structures, as well as transportation and utility lifelines, that are located on them or in their downslope paths.

Because landslides often occur without earthquakes, landslide hazards are more thoroughly discussed in a separate section of this chapter, see [Section 6.2](#).

### Levee Failure

Ground shaking in and around levees resulting from earthquakes 100 kilometers or more away can affect levee performance. The type of foundation the levee is constructed upon (such as peat or alluvium) will influence a levee's performance during a seismic event or under certain static loading conditions (see [Section 7.4, Levee Failure and Safety](#)).

### Earthquake Hazards: Tsunami

Tsunamis are large waves caused by sudden disturbances in the ocean, usually on the ocean floor. Tsunamis are commonly caused by fault rupture on the ocean floor or by underwater landslides. A separate section of this SHMP addresses this hazard (see [Section 7.3, Tsunami and Seiche Hazards, Vulnerability, and Risk Assessment](#)).

## 6.1.2 PROFILING EARTHQUAKE HAZARDS

### Recent Earthquake Events

Earthquakes large enough to cause moderate damage to structures—those around Magnitude 5.5—occur three to four times a year in California. For example, the Magnitude 6.5 San Simeon Earthquake of December 22, 2003 caused 2 deaths, 47 injuries, and \$263 million in damage. The Magnitude 6.5 Humboldt County Earthquake on January 9, 2010, resulted in zero deaths, 35 injuries, and \$43 million dollars in damage. The Magnitude 7.2 El Mayor Cucapah Earthquake (also known as the Sierra El Mayor Earthquake) of April 4, 2010 was located in Northern Baja California at the former mouth of the Colorado River. This event shook not only Mexicali and Tijuana but also a large part of Southern California and parts of southwestern Arizona and Nevada. There were two confirmed deaths in Mexicali and 100 persons were injured between Baja California and Imperial County California. The total estimated damage in Southern California from the El Mayor-Cucapah event was \$91 million while the total estimated damage between Southern California and Baja California was estimated to be \$1 billion with most of the damage affecting the agriculture industry and irrigation district in Baja California.

Strong earthquakes of Magnitude 6 to 6.9 strike California on an average of once every two to three years. An earthquake of this size, such as the 1994 Northridge Earthquake (Magnitude 6.7) or the 1983 Coalinga Earthquake (Magnitude 6.7), is capable of causing major damage, if the epicenter is near a densely populated area. The Northridge Earthquake caused over \$40 billion of disaster losses, 57 deaths, and 11,846 injuries, while the 2014 earthquake (Magnitude 6.0) in less densely populated area, caused \$87 million of disaster losses, 1 death, and 200 injuries.

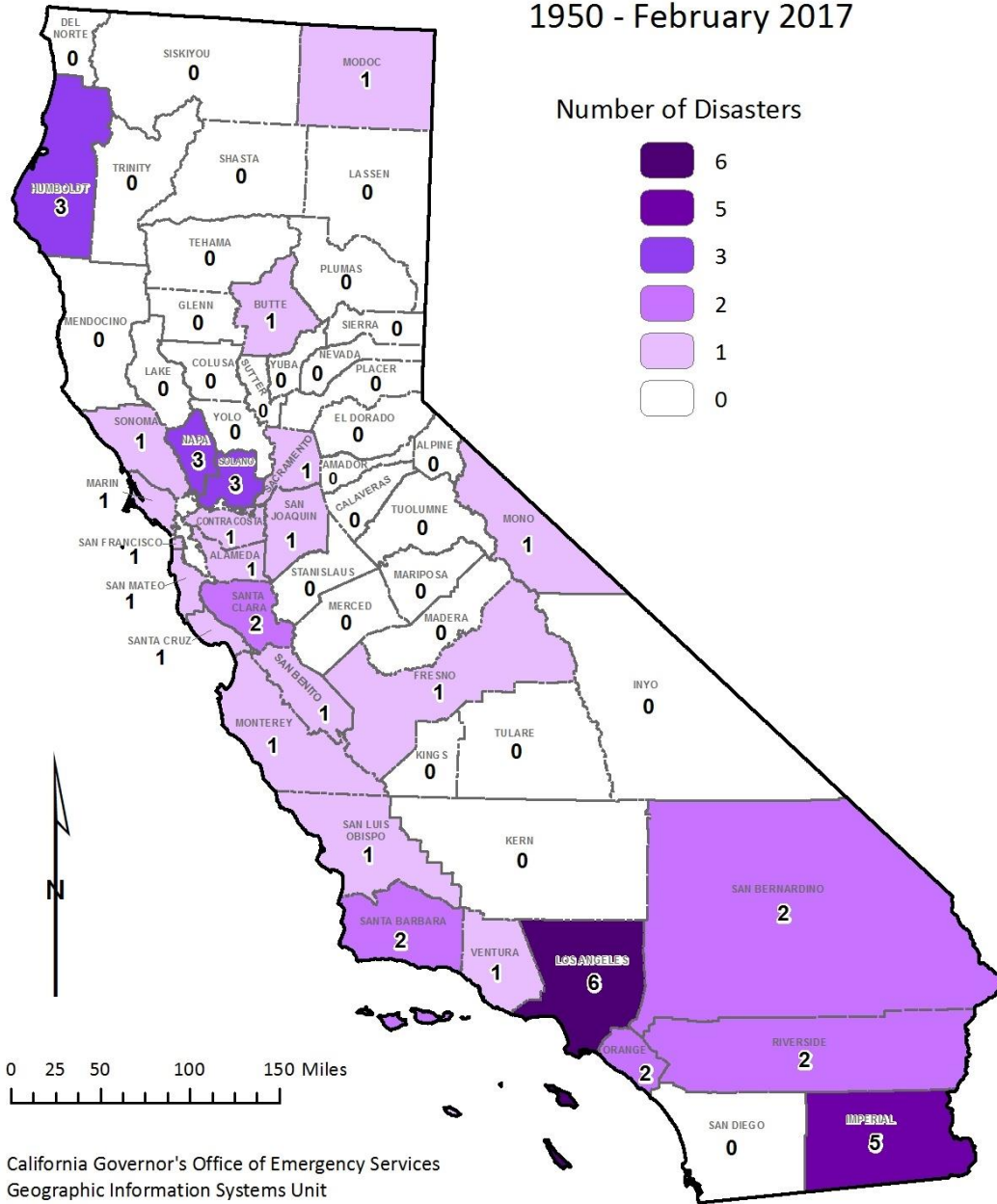
Major earthquakes (Magnitude 7 to 7.9) occur in California about once every 10 years. Two recent major earthquakes, the 1992 Landers Earthquake (Magnitude 7.3) and the 1999 Hector Mine Earthquake (Magnitude 7.1) caused extensive surface fault rupture but relatively little damage because they occurred in lightly populated areas of the Mojave Desert. In contrast, earthquakes of smaller magnitude but in densely populated areas, such as the 1989 Loma Prieta Earthquake (Magnitude 6.9), have caused extensive damage over large areas.

Map 6.B shows the following numbers of state- and federal-declared earthquake disasters by county (representing 26 of California's 58 counties):

- Los Angeles County – 6
- Imperial County – 5
- Humboldt, Napa, and Solano Counties – 3 in each county
- Orange, Riverside, San Bernardino, Santa Barbara, and Santa Clara Counties – 2 in each county
- Alameda, Butte, Contra Costa, Fresno, Marin, Modoc, Mono, Monterey, Sacramento, San Benito, San Francisco, San Joaquin, San Luis Obispo, San Mateo, Santa Cruz, Sonoma, and Ventura Counties – 1 in each county

Map 6.B: State and Federal Declared Earthquake Disasters, 1950-February 2017

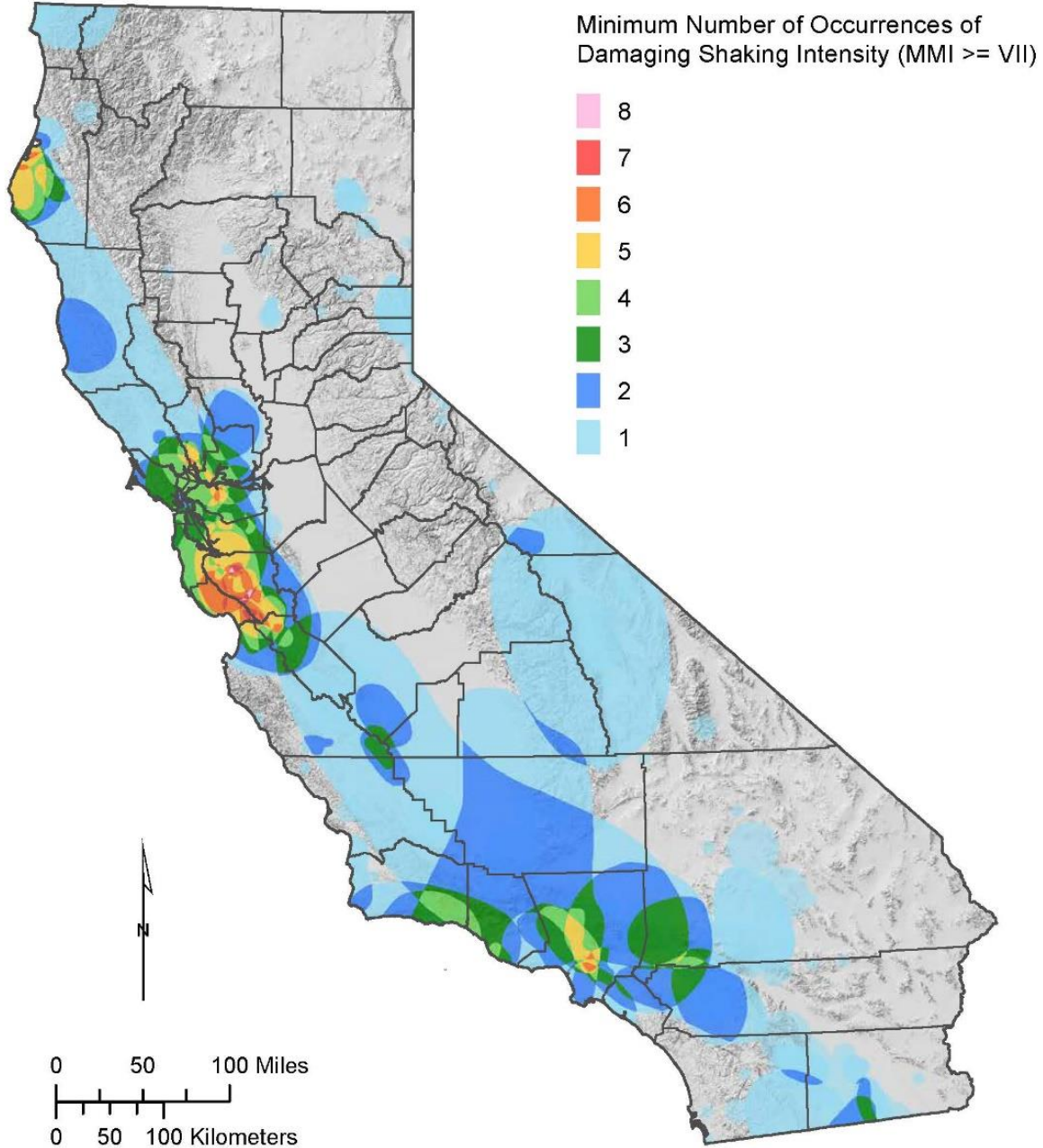
## State and Federal Declared Earthquake Disasters 1950 - February 2017



Map 6.B shows the distribution within California of state-proclaimed and federally declared earthquake disasters from 1950 to 2017. The distribution of disasters can be generally related to potential future earthquake shaking hazards levels in California.

**Map 6.C: Areas Damaged by Earthquakes, 1800-2017**

**Areas Damaged by Earthquakes  
(1800 - 2017)**



Source: California Geologic Survey

Map 6.C shows the numbers of historical occurrences of events described as Modified Mercalli Intensity (MMI) Scale VII or greater from 1800 to 2017. Such events notably have been concentrated along the San Andreas Fault system, particularly in the San Francisco Bay, Monterey Bay, and Humboldt County areas. However, a significant earthquake is expected in Southern California in the near future. Such an event would change this map significantly by including both larger areas and more occurrences of damage in Southern California.

## California's Catastrophic Earthquake Potential

Two of the largest historic earthquakes in California, the 1857 Fort Tejon Earthquake and the famous 1906 San Francisco Earthquake, were similar in magnitude (Magnitude 7.9 and Magnitude 7.8) and resulted from movement along the San Andreas Fault. Earthquakes of this size (Magnitude 7.7 to Magnitude 7.9) can cause more extensive damage over a larger area than the Magnitude 7.1 to Magnitude 7.4 earthquakes that have struck California in recent decades.

Although a great earthquake (Magnitude 8 or greater) has never been officially recorded in California, evidence suggests that one occurred in the early 18th century. Historical and geological data strongly indicate that a Magnitude 9 earthquake occurred in January 1700 on the Cascadia Subduction Zone, which extends north from Cape Mendocino in Northern California to British Columbia. An earthquake of this size is similar to the one that struck Alaska in 1964 and is capable of extensive damage over a very broad region.

## Current Views on Probability of Seismic Hazards Statewide

Based on the most recent earthquake forecast model for California, the USGS and other scientists estimate a 72-percent probability that at least one earthquake of Magnitude 6.7 or greater, capable of causing widespread damage, will strike the San Francisco Bay Area before 2044. For the Los Angeles region, the same model forecasts a 60-percent probability that an earthquake of Magnitude 6.7 or greater will occur before 2044.

These probabilities were updated with the 2014 National Seismic Hazards Map, which included a time-independent version of an earthquake forecast map of California. The map was completed so that information on seismic hazards in California would be consistent with the level of knowledge throughout the rest of the country. In 2014, the USGS and CGS released the time-dependent and time-independent versions of the Uniform California Earthquake Rupture Forecast (UCERF 3) model. These statewide peer-reviewed forecasts are considered the authoritative earthquake forecast for the State of California.

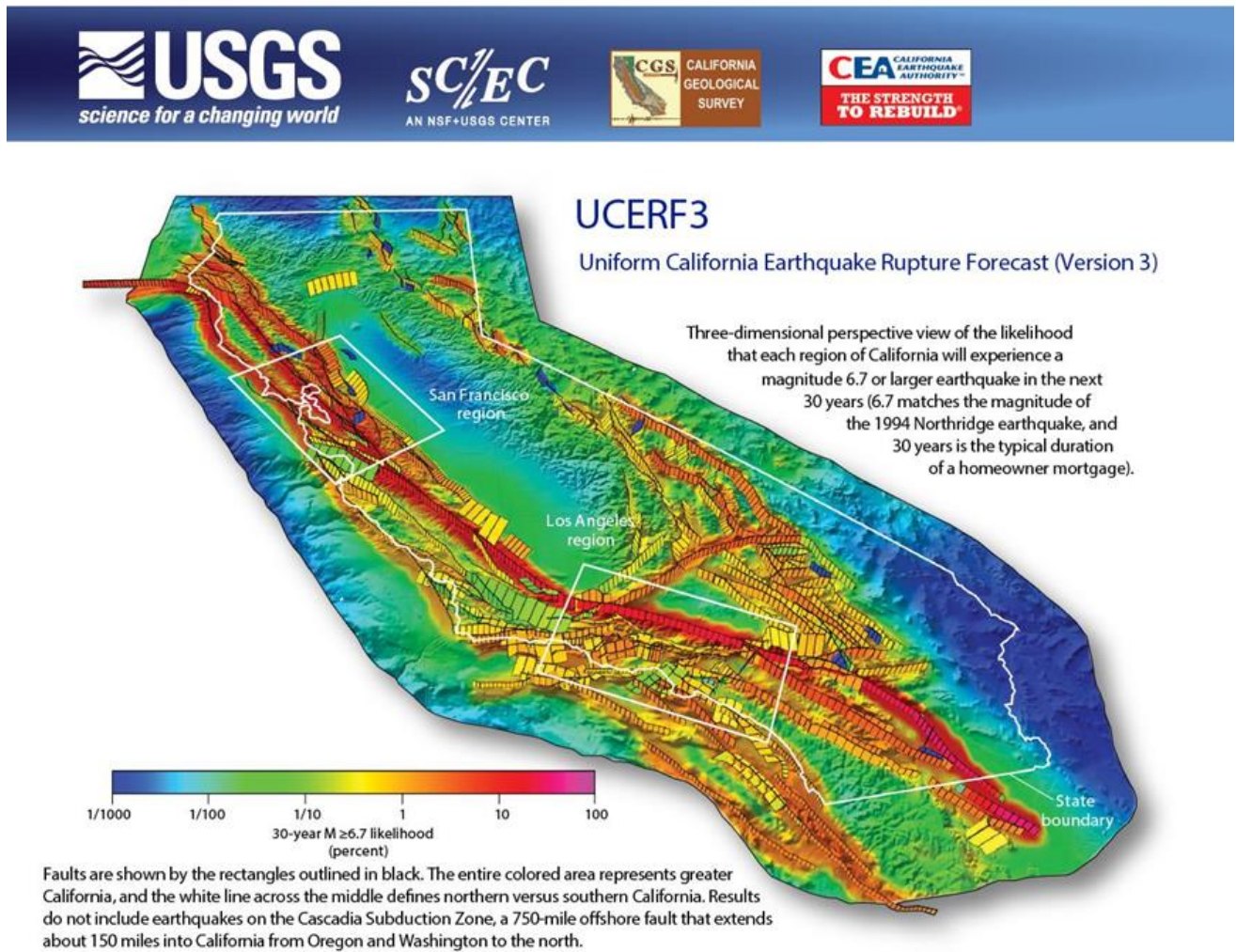
The UCERF 3 results have helped to reduce the uncertainty in estimated 30-year probabilities of strong ground motions in California. The success of the UCERF 3 project has led to interest in the continued development of short-term (less than 1 week) forecasting, appropriate for considering aftershocks, clustering of earthquakes, and earthquakes being triggered by other earthquakes. For more information about the UCERF program, visit: <http://www.scec.org/ucerf/>.

It is anticipated that the 2014 edition of the National Seismic Hazard Map and related documents will be incorporated into the 2019 California Building Code. This incorporation of seismic map documents will be considered for adoption as part of the 2019 California Building Standards Commission. The models are anticipated to be of great value in helping practitioners assess strong motion shaking throughout California on a regional basis for all classes of buildings and structures. For information on the California Earthquake Authority discussions regarding the impacts of these projects on the residential building stock in California, see [Section 6.1.5.2, Mitigation of Potential Building Losses](#).

These models were important in reducing uncertainty in ground motion for seismic hazard assessment throughout California. This reduction of uncertainty in ground motion helps practitioners assess risk potential for new and existing buildings and infrastructure.

Map 6.D depicts probabilities of various magnitude earthquakes greater than Magnitude 6.7 occurring in 30 years in various regions of the state. These probabilities include greater than 99 percent for a Magnitude 6.7 event, 93 percent for a Magnitude 7.0 event, 48 percent for a Magnitude 7.5 event, and 7 percent for a Magnitude 8.0 event.

Map 6.D: Probability of Earthquake Magnitude 6.7 or Greater Occurring in 30 Years, by Region



Source: United States Geological Survey Open File Report 2013-1165

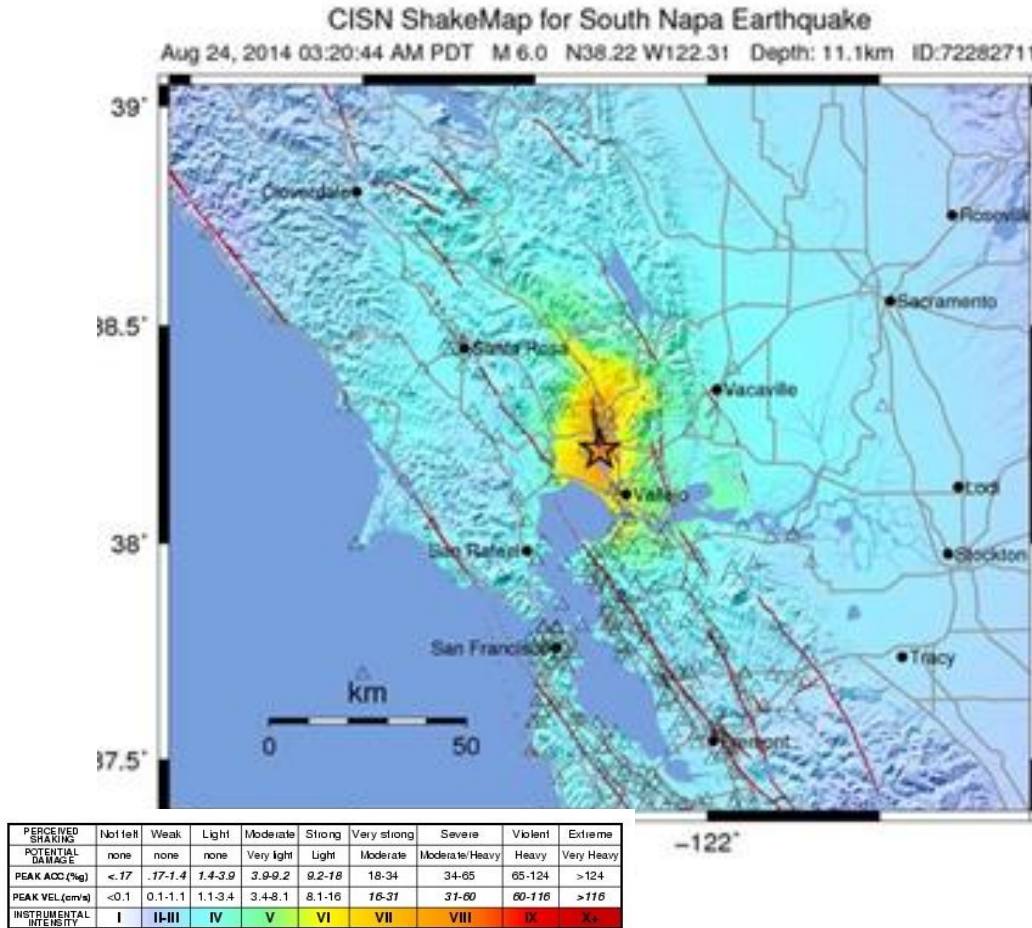
### Earthquake “ShakeMaps”

Earthquake shaking is measured by instruments called accelerometers that are triggered by the onset of shaking and record levels of ground motion at strong motion stations throughout the state operated by the California Integrated Seismic Network (CISN). CISN is composed of six core organizations: California Geological Survey (CGS), Caltech Seismological Laboratory, Berkeley Seismological Laboratory, U.S. Geological Survey (USGS) Menlo Park and Pasadena, and the California Governor’s Office of Emergency Services (Cal OES). CISN rapidly converts the data from the accelerometers into ShakeMaps to provide near-real-time maps of ground motion and shaking intensity following significant earthquakes. These measures are used to infer shaking intensity expressed as Modified Mercalli Intensity (MMI). To learn more about MMI, visit the following link: <https://earthquake.usgs.gov/learn/topics/mercalli.php>.

Based on actual measured motions, ShakeMaps, such as Map 6.E for the 2014 South Napa Earthquake, are a major step forward in guiding emergency response to earthquakes. They are used by emergency responders to evaluate the extent and variation of shaking within the area affected by an earthquake and to send resources to the areas that most likely sustained heavy damage. Simulated ShakeMaps are also generated for specific future earthquake

scenarios based on fault rupture and other geophysical models. Immediately following damaging earthquake events, ShakeMap-modeled intensity levels are the basis for HAZUS loss estimates.

**Map 6.E: ShakeMap for 2014 South Napa Earthquake**



In addition, more sophisticated models of earthquake shaking for a given place consider the potential for all future earthquakes on surrounding faults and their related ground motion affecting that place. Integrating all of the potential for ground motion statewide produces maps that show the long-term probabilistic seismic hazard anywhere in the state. Such maps help identify areas that are particularly vulnerable, which is useful in pre-disaster mitigation planning as well as post-disaster performance evaluations of prior mitigation projects. For more information about CISN, visit: [www.cisn.org](http://www.cisn.org).

### 6.1.3 ASSESSMENT OF STATE EARTHQUAKE VULNERABILITY AND POTENTIAL LOSSES

A 2006 study (Kircher, et al.) points out that, since the 1906 San Francisco Earthquake, the Bay Area region’s population has increased about ten-fold. Losses in the 1906 earthquake included 3,000 deaths, \$524 million in direct building losses in 1906 dollars (which would equal about \$42 billion in 2006 dollars), and 28,000 destroyed buildings, many by fire following the earthquake. It was estimated that a repeat of the 1906 earthquake in 2006 would result in 800 to 3,400 deaths, \$90 billion to \$120 billion in losses, and 90,000 to 127,000 extensively or completely damaged buildings.<sup>97</sup> Table 6.A shows earthquake losses from 1971 to 2018.

<sup>97</sup> Kircher, et al. “When the Big One Strikes Again – Estimated Losses due to a Repeat of the 1906 San Francisco Earthquake.” EERI Spectra Vol. 22, No. 52. April 2006.

**Table 6.A: Recent Earthquake Losses**

Earthquake	Date	Magnitude	Direct Losses <sup>a</sup>	Deaths <sup>d</sup>	Injuries <sup>d</sup>
San Fernando	February 9, 1971	6.6	\$2,200 <sup>b</sup>	58	2,000
Imperial Valley	October 15, 1979	6.5	\$70 <sup>b</sup>	0	91
Coalinga	May 2, 1983	6.7	\$18 <sup>b</sup>	1	47
Whittier Narrows	October 1, 1987	6.0	\$522 <sup>c</sup>	9	200+
Loma Prieta	October 17 1989	6.9	\$10,000 <sup>d</sup>	63	3757
Cape Mendocino	April 25, 1992	7.0	\$80 <sup>c</sup>	0	356
Landers/Big Bear	June 28, 1992	7.3	\$120 <sup>c</sup>	1	402
Northridge	January 17, 1994	6.7	\$46,000 <sup>b</sup>	57	11,846
Hector Mine	October 16, 1999	7.1	minor	0	11
San Simeon	December 22, 2003	6.5	\$263 <sup>e</sup>	2	46
Eureka/Humboldt	January 9, 2010	6.5	\$43	0	43
El Meyor Cucapah	April 4, 2010	7.2	\$91	0	91
South Napa	August 24, 2014	6.0 <sup>f</sup>	\$87 <sup>g</sup>	1 <sup>h</sup>	200 <sup>i</sup>

<sup>a</sup> Estimate in millions of dollars

<sup>b</sup> Federal Emergency Management Agency (FEMA) 1997; U.S. Office of Technology Assessment

<sup>c</sup> National Research Council, 1994

<sup>d</sup> California Governor's Office of Emergency Services (Cal OES)

<sup>e</sup> California Seismic Safety Commission (CSSC) 2004-02, 2004

<sup>f</sup> <https://earthquake.usgs.gov/earthquakes/eventpage/nc72282711#executive>

<sup>g</sup> [www.fema.gov/disasters](http://www.fema.gov/disasters)

<sup>h</sup> <http://www.usgs.gov/news/media-advisory-south-napa-earthquake-science-briefing>

<sup>i</sup> <http://www.usgs.gov/news/media-advisory-south-napa-earthquake-science-briefing>

### 6.1.3.1 ESTIMATING LOSSES FROM FUTURE EARTHQUAKES

Generating loss estimates provides the state with estimated figures for use in setting mitigation program priorities, identifying locations with greatest vulnerability, and guiding emergency response and recovery planning. Over the last few decades a number of scenarios have been developed for areas within the state for various purposes.

At \$40 billion in losses, the 1994 Northridge Earthquake was the most costly disaster of any type in California's history and still ranks as the third most costly disaster in U.S. history (behind Hurricane Katrina and Superstorm Sandy).

The annualized earthquake loss (AEL) is the estimated long-term value of earthquake losses to the general building stock in any single year in a specified geographic area (e.g., state, county, metropolitan area). According to the HAZUS Estimated Annualized Earthquake Losses for the United States (FEMA P-366 / April 2017), the AEL to the national building stock is \$6.1 billion per year. California represents the vast majority of this average annual loss, at 61 percent of such losses (\$3.7 billion per year). The West Coast (Oregon and Washington) accounts for an additional 12 percent of the total average annual loss in the U.S., with the remainder of the country (including Alaska, Hawaii, and the U.S. Territories) accounting for 27 percent. The high concentration of loss in California is consistent with the state's high seismic hazard and large structural exposure.

While building-related losses are a reasonable indicator of relative regional earthquake risk, it is important to recognize that these estimates are not absolute determinants of the total risk from earthquakes. This is because factors such as amount of debris generated and social losses including casualty estimates, displaced households, and shelter requirements need to be considered. Seismic risk also depends on other parameters not included herein, such as damages to lifelines and other critical facilities and indirect economic loss. When casualties, debris, and shelter data are aggregated by state, California accounts for over 60 percent of estimated debris generated, 64 percent of displaced households, and 63 percent of short-term shelter needs for the earthquake hazard with a 250-year return period.

Fifty-five metropolitan areas nationally, led by the Los Angeles and San Francisco Bay areas, account for 80 percent of the total AEL. Los Angeles County alone has about 22 percent of the total AEL, and the Los Angeles area and San Francisco Bay area together account for nearly 35 percent of the total AEL. As measured by the annualized earthquake loss ratio (AELR), which expresses estimated annualized loss as a fraction of the building inventory replacement value, many other California communities are within the top 20. El Centro is the metropolitan region with the highest AELR, followed closely by the San Jose and San Francisco metropolitan areas.

With HAZUS, a nationally applicable standardized methodology and Geographic Information Systems (GIS) modeling software developed by the Federal Emergency Management Agency (FEMA), it has become possible to estimate possible losses from future earthquakes in California using ShakeMap scenarios. HAZUS is a regional loss estimation tool that uses population and building data aggregated at a census tract level. Building value and construction cost estimates are adjusted to reflect regional variations. By combining ShakeMaps with a statewide computerized inventory of population and buildings using HAZUS, Cal OES has estimated casualty and damage losses from various potential earthquakes for the two largest metropolitan regions of the state.

However, several qualifications on the probable underestimation of these loss estimates should be made:

1. Use of Decennial Census. Cal OES used the Decennial Census as the basis for estimating population and building inventory. Greater-than-expected growth, increased property values, and construction costs since that time may mean that losses are underestimated.
2. Losses to Critical Infrastructure. Due to lack of critical infrastructure data in the HAZUS model, Cal OES did not include these potential loss estimates.
3. Recovery Costs. HAZUS addresses some recovery issues but does not estimate additional potential losses that may be experienced as a result of a lengthy recovery and reconstruction process resulting from a catastrophic event in an urban area.
4. Earthquake Shaking. The earthquake shaking modeled in ShakeMap scenarios is based on fault rupture models, ground motion attenuation relationships, geologic material velocity models, and other considerations. Because of the assumptions that go into these models, actual earthquake shaking intensities and the resulting losses will be more complex and variable.
5. Consideration of Aftershocks and Multiple Earthquakes. Omori's law of magnitude distribution describes the number of aftershocks relative to magnitude. An earthquake triggers a series of aftershocks, with a larger earthquake creating the potential for large aftershocks, and for greater total number of aftershocks. Then, each subsequent aftershock triggers its own series of aftershocks in an "epidemic" model. The HAZUS model cannot account for increased loss due to the increase in building fragility as a result of repeated exposure to earthquake shaking. Likewise, HAZUS cannot discount losses for any buildings already destroyed in prior shocks.

#### **Progress Summary 6.A: HAZUS Earthquake Loss Estimation for California**

**Progress as of 2018:** Earthquake loss estimation and planning scenarios quantify seismic risk based on seismic hazard and exposure and vulnerability of the built environment. Such studies need to be frequently updated because of continuing development of the built environment and evolving technology in earthquake ground motion prediction and seismic hazard assessments. The California Geological Survey (CGS) has developed and participated in the development of many planning scenarios since 1980. The CGS also updates its scenario- and probabilistic-based loss estimations when significant developments occur in ground motion hazard analyses and in the built environment.

Using the latest Hazards United States (HAZUS) default information for built environment and demographics, the CGS updated statewide annualized earthquake losses (AELs) for California in September 2016. This AEL update is based on ground motions from the 2014 update of the U.S. Geological Survey National Seismic Hazard Model.

The updated AEL estimated \$3.7 billion in potential losses, with 30 percent of the state’s potential loss occurring in Los Angeles County due to its very high economic exposure and population and proximity to many seismically active faults. To download the 2016 Update of HAZUS Annualized Earthquake Loss Estimates for California Report, visit: [http://www.conservation.ca.gov/cgs/rghm/loss/Pages/2016\\_Analysis.aspx](http://www.conservation.ca.gov/cgs/rghm/loss/Pages/2016_Analysis.aspx).

Map 6.F, from the 2016 HAZUS Annualized Earthquake Loss Estimates for California report, shows both annualized earthquake losses (AELs) for buildings and annualized percent loss. Eighty percent of the state’s AEL occurs in 10 of the state’s 58 counties: Los Angeles, Santa Clara, Alameda, Orange, San Bernardino, Riverside, Contra Costa, San Francisco, San Mateo, and San Diego.

**Map 6.F: Annualized Earthquake Loss, by County**

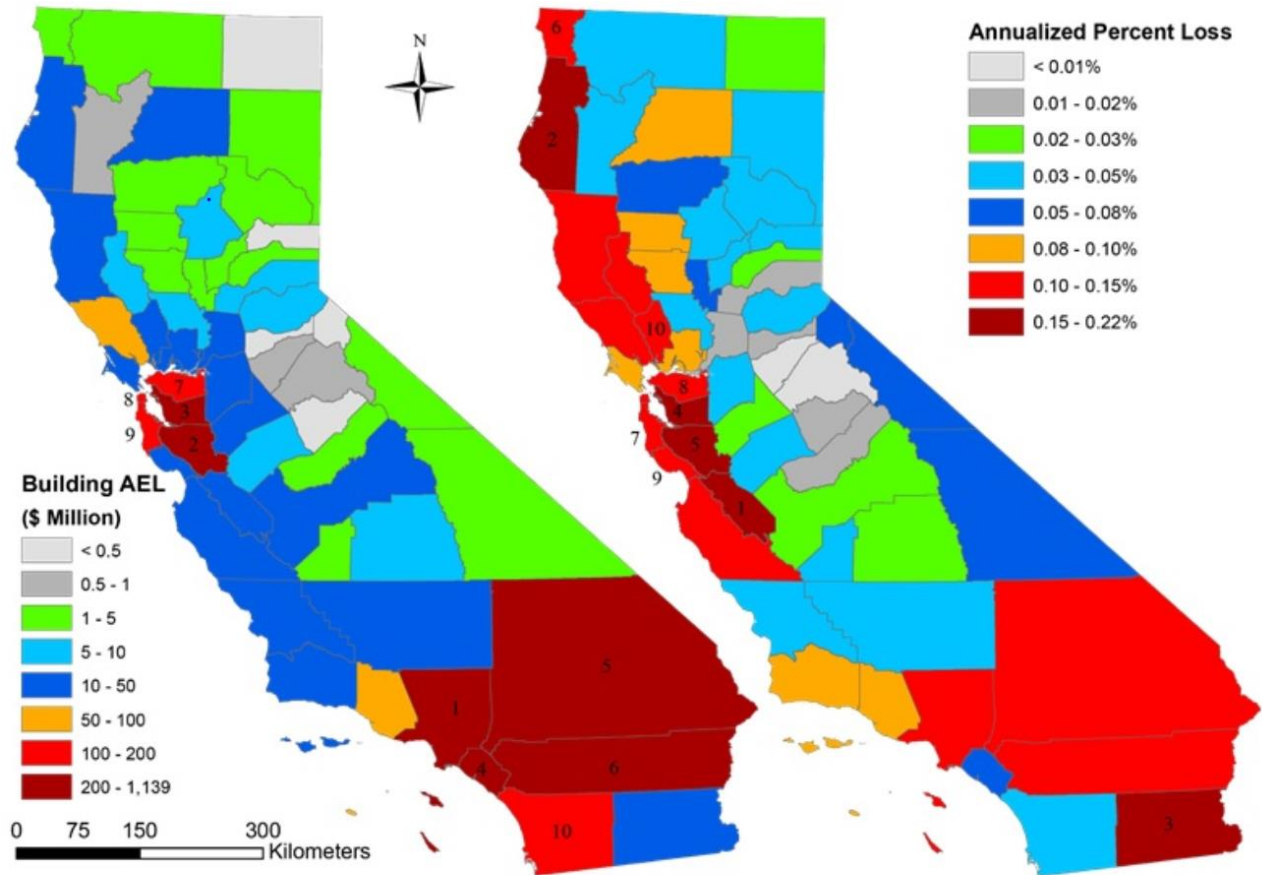


Figure 1. Distribution of building (a) annualized economic loss (AEL) and (b) annualized percent earthquake loss (APEL) in California by county (based on sensitivity case 1, site condition approximated using  $V_{S30}$  groups). The top 10 counties with the highest AEL (ranked by numbers in a) are Los Angeles, Santa Clara, Alameda, Orange, San Bernardino, Riverside, Contra Costa, San Francisco, San Mateo, and San Diego. More than 80% of the state total AEL occurs in the top 10 counties, and about 55% of the state total AEL occurs in the top 4 counties. The top 10 counties with the highest APEL (ranked as indicated by numbers in b) are San Benito, Humboldt, Imperial, Alameda, Santa Clara, Del Norte, San Mateo, Contra Costa, Santa Cruz, and Napa.

Source: Department of Conservation, California Geologic Survey, [http://www.conservation.ca.gov/cgs/Pages/Program-SHP/2016\\_Analysis.aspx](http://www.conservation.ca.gov/cgs/Pages/Program-SHP/2016_Analysis.aspx)

**Table 6.B: Projected Earthquake Scenario Losses, Northern California**

Potential Earthquake Scenarios <sup>a</sup>	M <sub>w</sub> <sup>b</sup>	Projected Building Damage	Projected Range of Deaths <sup>c</sup>	Projected Range of Injuries <sup>c</sup>
San Andreas Fault: Repeat of the 1906 San Francisco Earthquake <sup>c</sup>	7.8	\$98,328,305,100	220-7,851	427-1,953
San Andreas Fault: Santa Cruz, Peninsula, and North Coast Segments <sup>c</sup>	7.9	\$26,781,199,900	36-210	19-990
San Andreas Fault: Santa Cruz and Peninsula Segments <sup>d</sup>	7.5	\$22,708,915,200	28-158	14-768
San Andreas Fault: Santa Cruz Segment <sup>d</sup>	7.1	\$4,555,235,200	0-1	0-21
San Andreas Fault: Peninsula Segment <sup>d</sup>	7.2	\$15,945,699,900	4-22	2-181
Southern Hayward <sup>d,e</sup>	6.8	\$15,168,660,800	7-32	3-231
Northern Hayward <sup>d</sup>	6.6	\$8,011,156,100	1-5	1-63
Southern Hayward and Northern Hayward <sup>d</sup>	7.0	\$19,738,847,000	11-55	6-357
Rodgers Creek <sup>d</sup>	7.3	\$24,735,265,700	18-87	9-521
Southern Calaveras and Central Calaveras <sup>d</sup>	6.5	\$3,308,444,200	0-1	0-16
Northern Calaveras <sup>d</sup>	6.9	\$9,263,162,700	1-9	1-77
Southern, Central, and Northern Calaveras <sup>d</sup>	7.0	\$11,367,886,900	2-15	1-114
Concord <sup>d</sup>	6.5	\$7,515,843,500	8-38	4-194
Green Valley <sup>d</sup>	6.3	\$4,809,402,700	0-1	0-32
Concord and Green Valley <sup>d</sup>	6.8	\$6,798,081,100	2-9	1-71
San Gregorio <sup>d</sup>	7.5	\$9,053,091,400	2-12	1-97
Mount Diablo <sup>d</sup>	6.7	\$7,901,880,900	1-8	0-73

Source: Produced by Cal OES GIS, based on data from HAZUS and California Geological Survey earthquake scenarios

<sup>a</sup> Based on earthquake scenarios as of August 2018

<sup>b</sup> M<sub>w</sub> is an earthquake magnitude scale

<sup>c</sup> Range of deaths/injuries represent three time-of-day scenario intervals (2am, 2pm, 5pm)

<sup>d</sup> FEMA- Region IX, 2018, Southern California Catastrophic Earthquake Plan, "Hazus: Earthquake Global Risk Report

<sup>e</sup> A HAZUS run of the 1868 Southern Hayward scenario was not performed due to insufficient ShakeMap data. A comparable scenario—the Southern Hayward M6.8 scenario—was run as a substitute.

Table 6.B and Table 6.C provide total building damage dollar loss estimates for 17 separate possible earthquake scenarios in Northern California and 14 in Southern California. Table 6.B reflects updated figures from the previously cited Charles Kircher study<sup>98</sup> in 2006, which modified HAZUS data with customized, more locally accurate data producing two scenarios, one for a repeat of the 1906 San Francisco Earthquake and the other for a projected alternative scenario Magnitude 7.9 earthquake in the San Francisco Bay region and surrounding counties. This scenario portraying a repeat of the 1906 San Francisco Earthquake has been updated to reflect an estimated total dollar loss of over \$98 billion.

<sup>98</sup> Kircher, et al. "When the Big One Strikes Again – Estimated Losses due to a Repeat of the 1906 San Francisco Earthquake." EERI Spectra Vol. 22, No. 52. April 2006.

**Table 6.C: Projected Earthquake Scenario Losses, Southern California**

Potential Earthquake Scenarios <sup>a</sup>	Mw <sup>b</sup>	Projected Building Damage	Projected Range of Deaths <sup>c</sup>	Projected Range of Injuries <sup>c</sup>
ShakeOut Scenario 2008 <sup>e</sup>	7.8	\$30,359,868,100	233-1,395	129-4,627
San Andreas Fault: Repeat of 1857 Earthquake <sup>d,e</sup>	7.8	\$17,215,858,700	84-636	46-2,124
Puente Hills Fault <sup>d</sup>	7.1	\$106,386,098,000	721-3,533	376-11,709
Newport-Inglewood <sup>d</sup>	6.9	\$44,490,764,700	114-495	60-2,033
Palos Verdes <sup>d</sup>	7.1	\$26,257,763,500	51-233	27-949
Whittier Fault <sup>d</sup>	6.8	\$21,780,360,100	7-49	4-360
Verdugo Fault <sup>d</sup>	6.7	\$32,125,450,300	49-231	26-1,046
San Andreas Fault: Southern Rupture <sup>d</sup>	7.4	\$13,922,337,300	51-246	29-908
Santa Monica <sup>d</sup>	6.6	\$22,310,270,900	12-36	7-290
Raymond Fault <sup>d</sup>	6.5	\$22,566,981,900	13-58	7-375
San Joaquin Hills <sup>d</sup>	6.6	\$21,965,633,000	26-129	14-620
Rose Canyon <sup>d</sup>	6.9	\$13,116,742,700	24-81	12-385
San Jacinto <sup>d</sup>	6.7	\$6,788,267,400	6-33	4-181
Elsinore Fault <sup>d</sup>	6.8	\$4,125,402,300	1-9	1-57

Source: Produced by Cal OES GIS, based on data from HAZUS and California Geological Survey earthquake scenarios

<sup>a</sup> Based on earthquake scenarios as of August 2018

<sup>b</sup> Mw is an earthquake magnitude scale

<sup>c</sup> Range of deaths/injuries represent three time-of-day scenario intervals (2am, 2pm, 5pm)

<sup>d</sup> FEMA- Region IX, 2018, Southern California Catastrophic Earthquake Plan, "Hazus: Earthquake Global Risk Report"

<sup>e</sup> 1857 Fort Tejon Earthquake Special Report, 2007, Risk Management Solutions

The 2007 SHMP estimated maximum potential earthquake building damage loss to state-owned and leased facilities using best available data. Of the total 24,313 state-owned and -leased buildings, Table 6.D, in [Section 6.1.3.3](#), identifies total risk exposures of \$48 billion for 15,255 buildings in areas potentially subject to Peak Ground Acceleration (PGA) of 31 to 175 percent (g) in an earthquake and \$26 billion for buildings in areas subject to PGA of 11- to 30-percent (g).

Note that these figures overstate potential losses for two reasons: 1) earthquakes are centered within one region or another (and do not occur in all regions at once), and 2) only a portion of the inventory within a region affected by a large magnitude earthquake would suffer building collapse or substantial damage. However, since the science of earthquake prediction is in its infancy and the location and magnitude of damaging earthquakes are essentially unknown, this broad inventory provides an indication of maximum exposure, which should inform state policy-makers and managers on the scope of potential seismic upgrades needed for continuity of operations.

## 2016 Bay Area Earthquake Plan

The Bay Area Earthquake Plan (BAEP) was developed by the U.S. Department of Homeland Security (DHS)/Federal Emergency Management Agency (FEMA) Region IX and the California Governor's Office of Emergency Services (Cal OES) with guidance from a Senior Leader Steering Committee that consisted of representatives from FEMA Region IX and Cal OES and the following entities: American Red Cross (ARC), California National Guard (CNG), Bay Area Urban Area Security Initiative (UASI), California Utilities Emergency Association (CUEA), 16 Bay Area counties, California Health and Human Services Agency (CHHS), U.S. Department of Defense (DOD) Defense Coordinating Element, and California Highway Patrol (CHP). Additionally, the BAEP was prepared through the cooperation and involvement of more than 70 local, regional, state, federal, and private sector entities.

Scenarios were developed by FEMA to inform the preparation of the BAEP. Published in 2016, the BAEP is an update to the San Francisco Bay Area Earthquake Readiness Response: Concept of Operations Plan dated September 23, 2008 and was developed to describe the joint state and federal response to a catastrophic earthquake in the Bay Area.

FEMA Hazards United States (HAZUS) modeling was completed for two severe earthquake scenarios in the Bay Area: a Magnitude 7.8 earthquake occurring along the San Andreas Fault and a Magnitude 7.0 earthquake occurring along the Hayward Fault. Both models show areas of violent and very violent shaking in densely populated areas. Figure 6.A depicts the HAZUS modeling results for damage, injuries, and other impacts.

**Figure 6.A: FEMA HAZUS Modeling**

SCENARIO	POPULATION	DEATHS	TRAUMA	HOSPITALIZED	ED	OUTPATIENT	EMS TRANSPORTS
Hayward	6,119,027	464	121	606	21,653	38,509	1,455
San Andreas	7,748,954	2,550	566	2,401	82,971	139,942	7,270
	BUILDINGS	Damage Complete	Damage Extensive	Damage Moderate	Debris	Economic Loss	
Hayward	3,038,798	13,557	39,886	150,800	14.4M tons	\$54 billion	
San Andreas	3,085,867	13,357	59,005	112,363	10M tons	\$60.5 billion	
	Households	Day 1 w/o Power	Day 3 w/o Power	Day 7 w/o Power	Displaced Households	Short-term Shelter	
Hayward	3,597,846	38%	17%	5.4%	76,501	55,295	
San Andreas	3,679,700	56%	32%	14.5%	49,774	29,151	
	Households	Day 1-3 w/o Water	Day 7 w/o Water	Day 30 w/o Water	Day 90 w/o Water		
Hayward	3,597,846	47%	43%	36%	25%		
San Andreas	3,679,700	60%	58%	48%	30.5%		

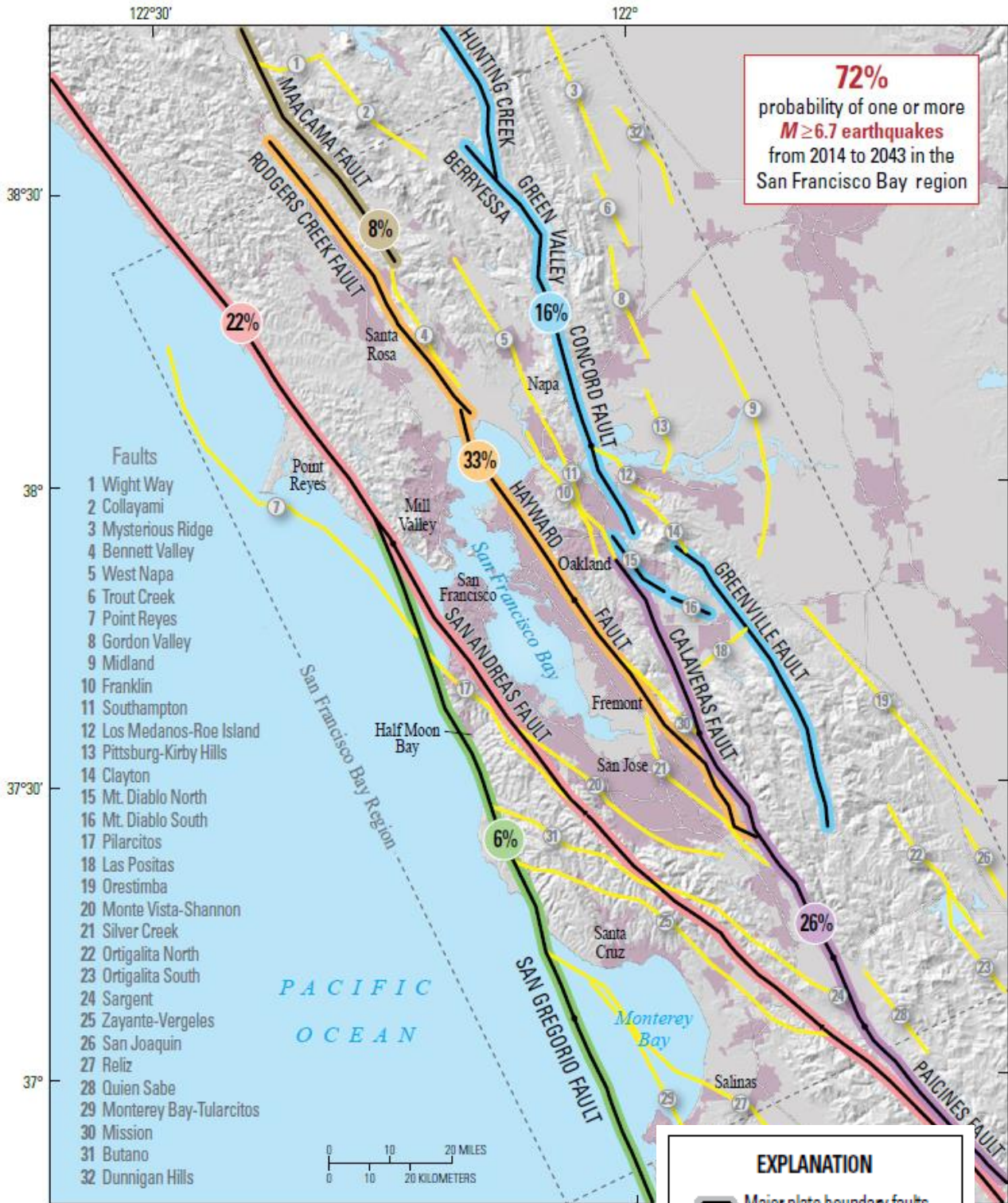
Source: Bay Area Earthquake Plan, 2016

For additional information, visit: <http://www.caloes.ca.gov/cal-oes-divisions/planning-preparedness/catastrophic-planning>. Or to download the BAEP, visit: [http://www.caloes.ca.gov/PlanningPreparednessSite/Documents/BayAreaEQConops\(Pub Version\) 2016.pdf](http://www.caloes.ca.gov/PlanningPreparednessSite/Documents/BayAreaEQConops(Pub Version) 2016.pdf).

Map 6.G depicts active geologic faults in the San Francisco Bay region, including the Hayward Fault, along with earthquake probabilities on these faults. The 72 percent probability of a Magnitude 6.7 or greater earthquake in the region includes well-known major plate-boundary faults, lesser-known faults, and unknown faults. The percentage shown within each colored circle is the probability that a Magnitude 6.7 or greater earthquake will occur somewhere on that fault system by the year 2043. The probability that a Magnitude 6.7 or greater earthquake will involve one of the lesser known faults is greater than or equal to 13 percent.<sup>99</sup>

<sup>99</sup> Aagaard and others, 2016

Map 6.G: Earthquake Outlook for the San Francisco Bay Region 2014-2043



Source: HayWired, Volume 1: <https://pubs.er.usgs.gov/publication/sir20175013v1>

## Survey Science Application for Risk Reduction Program and the HayWired Earthquake Scenario

The HayWired scenario is the latest in a series of projects led by the USGS Science Application for Risk Reduction (SAFRR) Program, which focuses on potential impacts when the Hayward Fault again ruptures through the east side of the San Francisco Bay region, as it last did in 1868.

Twelve large earthquakes have occurred on the Hayward Fault over the past 1,900 years, with the most recent nearly 150 years ago. There is a 1 in 3 chance of a Magnitude 6.7 or larger earthquake on the Hayward Fault, or the adjoining Rodgers Creek Fault, in the next 30 years. HayWired anticipates the impacts of a hypothetical Magnitude 7.0 earthquake on the Hayward Fault, which runs through the densely urbanized corridor of the East Bay in the San Francisco Bay region and is among the most active and dangerous in the United States.

This hypothetical earthquake is only one of many plausible events that could be the region's next big earthquake. The scenario name "HayWired" speaks to the threat of earthquakes on the Hayward Fault and the vulnerabilities and strengths posed by the interconnectedness of the bay region's people, utilities, roads, and economy—including the digital economy. The scenario was released in two volumes, with a third volume pending release in late 2018.

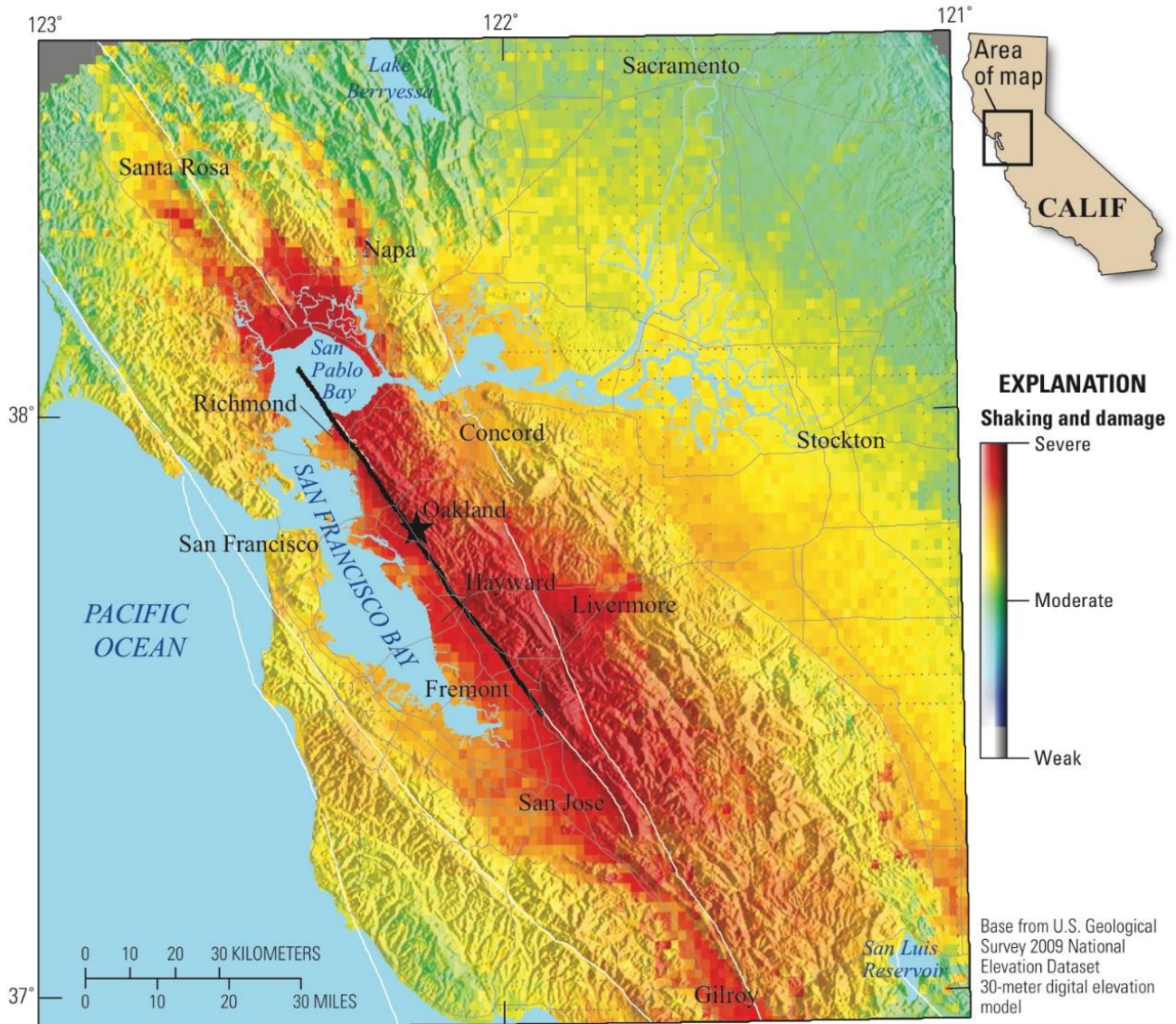
Volume 1, released in 2017, details the earthquake science and hazards information of the scenario, including the ground rupture model and analyses of potential co-seismic and post-seismic slip along the faults as well as liquefaction and earthquake-generated landslides around the region. Volume 2, released on April 18, 2018, the anniversary of the Magnitude 7.6 1906 San Francisco Earthquake, focuses on the immediate impacts on people, buildings, and infrastructure, including fires that erupt in the aftermath of such a major earthquake. Volume 3 will focus primarily on impacts on information and communications technology, along with effects on jobs and the regional economy.

The HayWired scenario earthquake occurs at 4:18 p.m. on April 18, 2018, is centered in Oakland, and ruptures both northward and southward along the Hayward Fault for about 52 miles. East Bay cities—from Richmond in the north to Fremont in the south—are hardest hit by violent ground shaking, but strong shaking is felt throughout the San Francisco Bay region. Map 6.H shows the simulated shaking intensity and damage severity of the HayWired scenario. The epicenter or mainshock location in Oakland is denoted on the map with a star.

The HayWired scenario earthquake results in 800 deaths and 18,000 injuries from building and structural damage caused by ground shaking and liquefaction hazards. More than 2,500 people in the region could require rescue from collapsed buildings, and more than 22,000 people might need to be rescued from stalled elevators. Property damage and direct business disruption losses due to ground shaking damage, liquefaction, and landslides from the mainshock and aftershock sequence are estimated to be more than \$82 billion (in 2016 dollars). Twenty percent of the shaking damage to buildings accrues from aftershocks. However, damage from the mainshock could render older, steel-frame, high-rise office buildings and newer reinforced-concrete residential buildings in downtown Oakland and San Francisco unusable for as long as 10 months.

Potable water systems in most of the region would be affected, but East Bay residents could lose water service for six weeks (some for as long as six months). Damage from the HayWired mainshock could trigger up to 400 fires that would kill hundreds more people, destroy the equivalent of 52,000 single-family homes, displace more people from their homes, and cause property losses approaching \$30 billion. Over 400,000 people could be displaced from their homes and communities due to residential building damage and extended infrastructure outages.

**Map 6.H: HayWired Scenario Ground Shaking for the Hypothetical Mainshock Magnitude 7.0 Earthquake on Hayward Fault**

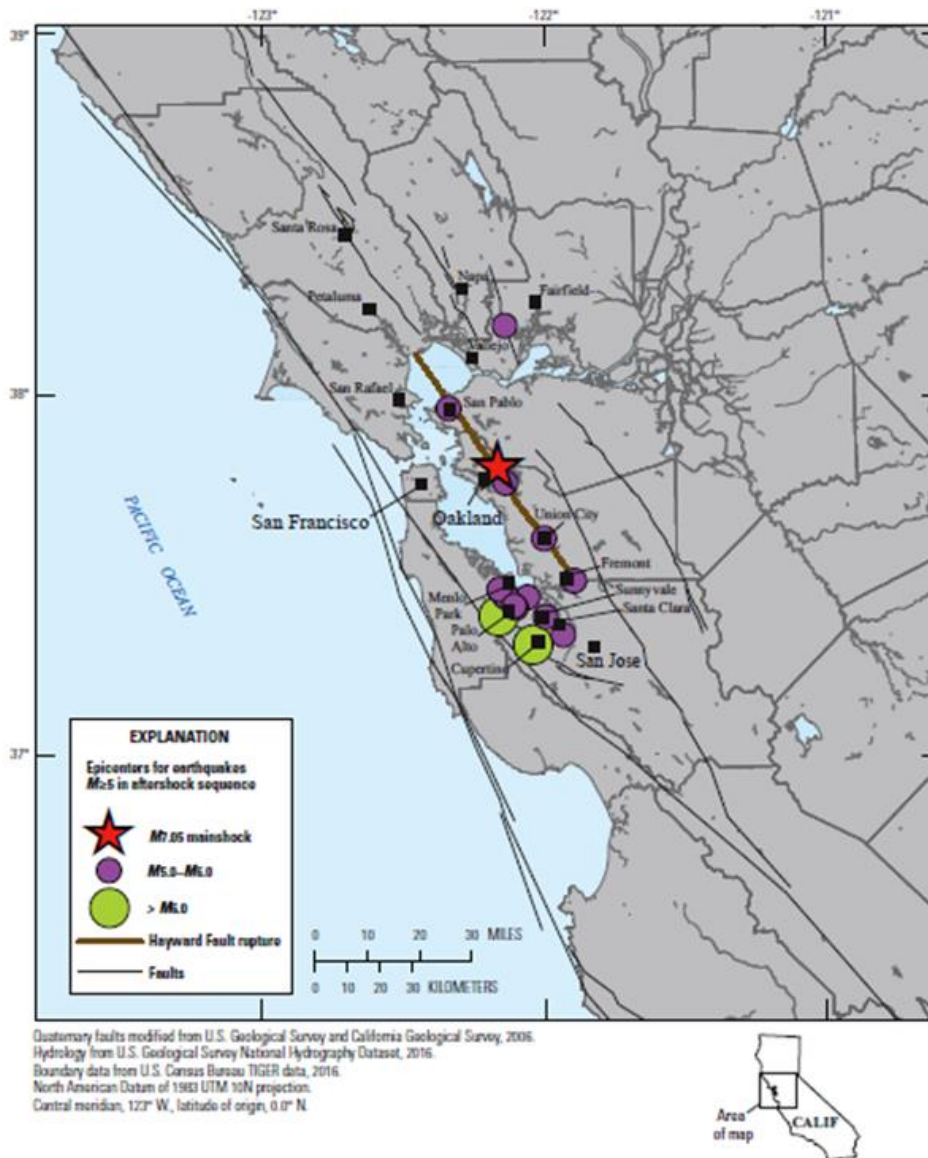


Source: U.S. Geological Survey, Haywired Earthquake Scenario reports, <https://pubs.er.usgs.gov/publication/sir20175013/>

The HayWired scenario also includes a sequence of hypothetical aftershocks happening in the minutes to years following the mainshock; 175 earthquakes of Magnitude 4 or larger and 14 earthquakes of Magnitude 5 or larger occurring over a two-year period.

Map 6.I shows the locations of the 14 Magnitude 5 or larger aftershocks in the scenario sequence. The largest hypothetical aftershock is a Magnitude 6.4 earthquake that occurs on October 1, 2018 and is centered in Cupertino. The HayWired scenario mainshock produces ground surface displacement across the fault of nearly 8 feet in the Richmond area and 3 to 4 feet at many locations from Berkeley to Hayward.

Map 6.I: Epicenters to Magnitude 5 or larger Aftershocks in the HayWired Scenario



Source: U.S. Geological Survey, Haywired Earthquake Scenario reports, <https://pubs.er.usgs.gov/publication/sir20175013/>

The HayWired team is building on the engineering analyses to further explore the societal consequences of the scenario. These studies will be released in Volume 3 of the scenario in October 2018, around the 29th anniversary of the Magnitude 7.1 Loma Prieta Earthquake, the last major earthquake to strike the region. The studies will review impacts on information and communications technology, effects on jobs and the regional economy, and issues for community recovery, including population displacement, social vulnerability, interim housing, and financing for long-term recovery planning.

The USGS and its partners in the HayWired Coalition and the HayWired Campaign are working to energize residents and businesses to engage in new and ongoing efforts to prepare the region for such a future earthquake. The Outsmart Disaster website (<https://outsmartdisaster.com>) provides actionable science for making informed decisions.

The HayWired Earthquake Scenario reports can be found at: <https://pubs.er.usgs.gov/publication/sir20175013/>.  
The HayWired Earthquake Scenario movie is at: <https://www.youtube.com/embed/aRLb3PmiYFc>.

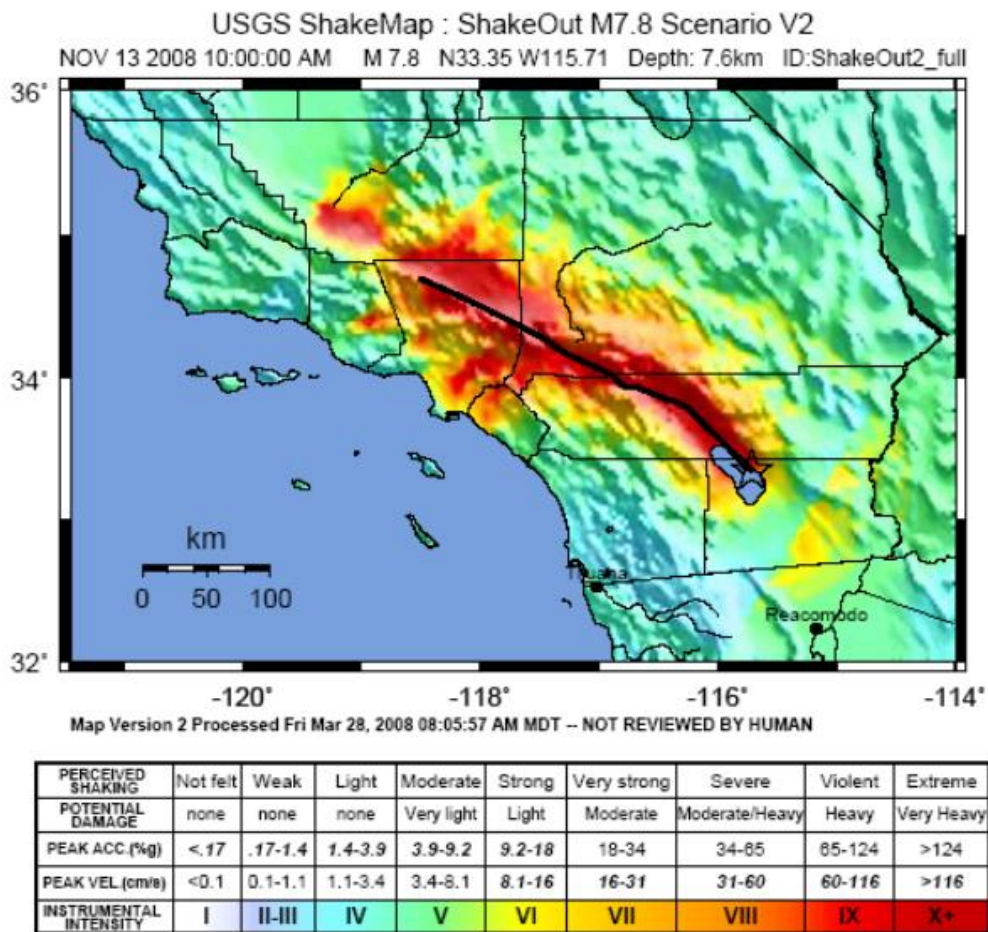
### The Great California ShakeOut Scenario

An effort to integrate science and disaster management at the federal level, the Multi-Hazards Demonstration Project was initiated by the USGS with a five-year pilot project in 2006. The project’s goal is to improve California community’s resiliency to earthquakes, floods, wildfires, tsunamis, and other hazards. That goal is being accomplished by applying science to community decision-making and emergency response, particularly through the use of a collaborative process and multi-hazard frameworks to create scenarios. The project is intended to help communities reduce their natural hazard threats by directing new and existing science toward identifying significant vulnerabilities and producing innovative hazard and risk communication products. These comprehensive and well-constructed “what-if” hazard scenarios are put to use in assessing and practicing mitigation preparedness, response, and recovery planning.

The ShakeOut Scenario, completed in May 2008 with hundreds of partners, was the first major product of the USGS Multi-Hazards Demonstration Project. This scenario designed a plausible large earthquake on the southern San Andreas Fault and then studied the effects of fault rupture and shaking as well as secondary hazards including liquefaction and landslides. The scenario considered direct physical impacts as well as long-term, social, cultural, and economic consequences.

Map 6.J is a USGS “ShakeMap” created for the ShakeOut Scenario showing the geographic distribution of shaking levels on a Modified Mercalli Scale for a hypothetical Magnitude 7.8 earthquake with a 200-mile rupture along the southern San Andreas Fault starting in the Salton Sea and progressing northward.

**Map 6.J: Great ShakeOut Magnitude 7.8 Earthquake Scenario on Southern San Andreas Fault**



Source: U.S. Geological Survey

To review the initial ShakeOut Scenario report, visit the USGS Earthquake Hazards Program website: <https://pubs.usgs.gov/of/2008/1150>.

The first Great ShakeOut earthquake drill, based on the ShakeOut Scenario, was performed as part of the Golden Guardian exercise in California in 2008. Since then the drills have evolved into an annual statewide exercise, which has led to improved preparedness through better understanding of possible disaster outcomes. For more information on the Great California Shakeout Drill Program, see Progress Summary 6.L.

Immediately after publication, it was clear that the ShakeOut Scenario made a difference. It encouraged new discoveries and applications in research fields as diverse as earthquake physics and disaster economics, broadening the foundation for future advances. Most importantly, it inspired the largest-ever participation in earthquake preparedness drills, among both the emergency response community and the general public, across the country and around the globe.

In January 2012, this Southern California pilot project evolved into the national Science Application for Risk Reduction (SAFRR) project, which has launched the ShakeOut, ARkStorm, and SAFRR Tsunami scenarios. The latest SAFRR project, HayWired, will be launched in 2018.

For more information regarding the HayWired, ShakeOut, ARkStorm, and SAFRR Tsunami Scenario projects, visit the USGS website: [https://www.usgs.gov/science-explorer-results?es=SAFRR&classification=science\\_project](https://www.usgs.gov/science-explorer-results?es=SAFRR&classification=science_project).

Map 6.K: Earthquake Shaking Hazard Affecting Buildings

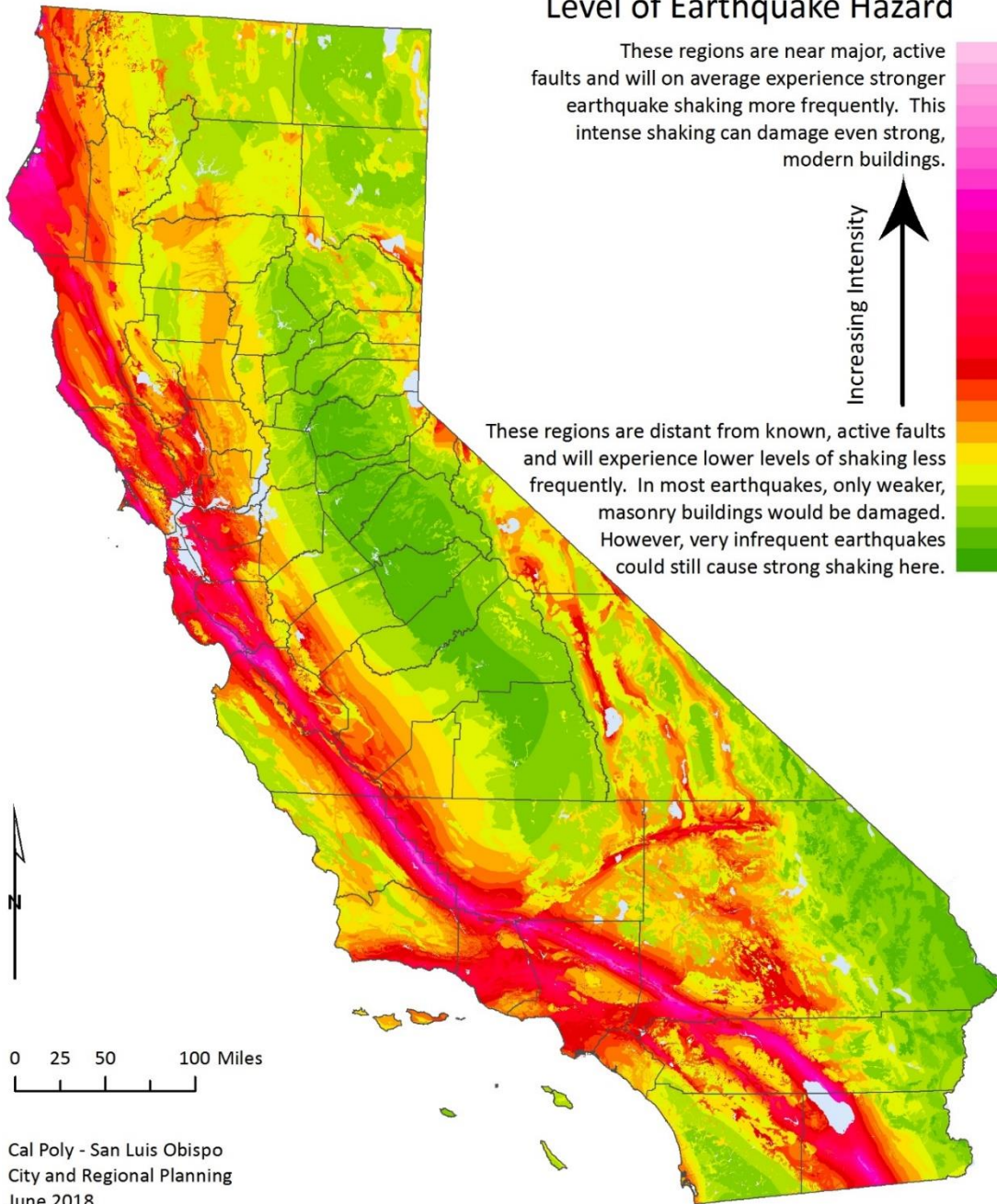
# Earthquake Shaking Hazard

## Level of Earthquake Hazard

These regions are near major, active faults and will on average experience stronger earthquake shaking more frequently. This intense shaking can damage even strong, modern buildings.



These regions are distant from known, active faults and will experience lower levels of shaking less frequently. In most earthquakes, only weaker, masonry buildings would be damaged. However, very infrequent earthquakes could still cause strong shaking here.



Cal Poly - San Luis Obispo  
City and Regional Planning  
June 2018

1.0 second spectral acceleration with 2% probability of exceedance in 50 years

This information was produced by the Department of Conservation, California Geological Survey and is protected by the United States Copyright Law. For information, contact the California Department of Conservation, California Geological Survey.

Created by: C. Schuldt (6.J.-Earthquake Shaking Hazard Affecting Buildings.mxd)

Map 6.K shows the distribution of earthquake shaking hazards affecting buildings, according to the CGS, USGS, and others. The most intense potential shaking areas parallel the coast between the borders with Mexico and Oregon, primarily along the San Andreas Fault and the Cascadia Subduction Zone.

### 6.1.3.2 EARTHQUAKE VULNERABLE AREAS AND POPULATIONS

Earthquake vulnerability is primarily based upon population and the built environment. Urban areas with high earthquake hazard potential tend to be the most vulnerable, while uninhabited areas generally are less vulnerable. In the past, the CGS and USGS have done considerable work using GIS technology to identify populations in areas with high seismic hazard.

Hurricane Katrina and other recent disaster events have brought to the public's attention the increased vulnerability of groups within the general population that may have fewer or differential access to resources, linguistic isolation, or less mobility than others, resulting in greater vulnerability to hazards events, such as earthquakes.

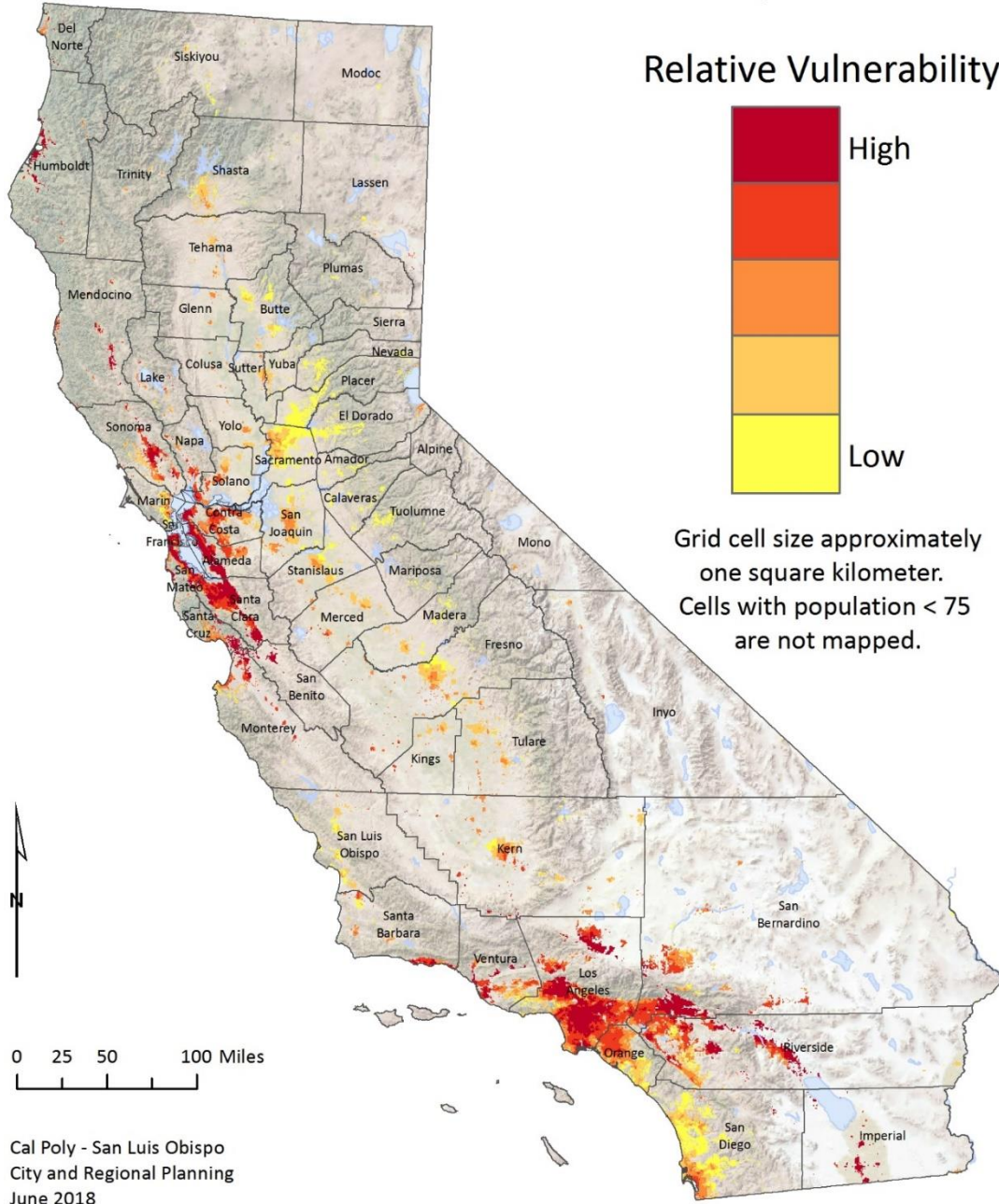
Map 6.L shows high concentrations of socially vulnerable populations throughout high earthquake hazard areas in the state's most heavily populated counties of Southern California, the Monterey Bay Area, and the San Francisco Bay Area. For an expanded discussion of social vulnerability, see [Section 4.4](#).

Unfortunately, the number and variations of all potential earthquakes are so large that it is not possible to develop scenarios for all of them, nor would it be possible to rank them by importance if such scenarios were developed. To get an idea of the overall scope of the risk of losses from earthquakes and to determine which areas are most vulnerable, the CGS and USGS use an alternate approach based on probabilistic seismic hazard analysis (PSHA), which considers all possible earthquakes on all possible sources and then evaluates the effects of this modeled shaking on inventories of structures that are in FEMA's HAZUS computer program.

Past earthquakes may not provide a realistic estimate of future earthquakes' effects. Large earthquakes in lightly populated regions, such as Landers and Hector Mine, show the potential earthquake shaking from major earthquakes, while moderate earthquakes in populated areas, particularly Northridge, give a sense of California's vulnerability to earthquake shaking. A major earthquake near one of California's urban centers could cause unprecedented losses.

Map 6.L: Earthquake Hazard and Social Vulnerability

# Population/Social Vulnerability with Earthquake Hazard



Cal Poly - San Luis Obispo  
City and Regional Planning  
June 2018

EQ hazard information from the Department of Conservation, California Geological Survey is protected by the United States Copyright Law. For information, contact the California Department of Conservation, California Geological Survey.

Population data source: Source: ORNL LandScan 2015 Global Population Database. UT-Battelle, LLC; 2015 American Community Survey (ACS) 5-year estimates.

Created by: C. Schuldt (4.J & 6.K - Pop-Soc Vuln with Earthquake Hazard.mxd)

### 6.1.3.3 ESTIMATING EARTHQUAKE LOSSES TO STATE-OWNED AND LEASED BUILDINGS

#### Overview

Although multiple state databases exist for state-owned, -leased, and -operated facilities, there is no single statewide data source on these crucial resources. Given the size and complexity of California's economy and extent of its infrastructure, together with its inherent earthquake vulnerability, the problem of estimating potential dollar losses for state-owned and -operated facilities is an overwhelming economic modeling challenge.

A reasonable representation of a worst-case scenario for dollar losses for state-owned facilities might be reflected in a repeat of any of the great earthquakes experienced in the past two centuries. In light of California's catastrophic earthquake potential, a Magnitude 7.9 earthquake could be said to represent the worst-case dollar loss scenario for state-owned, -leased, or -operated facilities—far worse than dollar losses from disasters triggered by any other hazards including the other primary hazards, flooding and wildfires.

**Table 6.D: Estimating Earthquake Dollar Loss for State Owned and Leased Buildings, as of 2007**

	State Ownership Status	Number of Buildings	Square Feet	\$ Value at Risk (billions)
Low: 0-10%g Peak Ground Acceleration <sup>a</sup>	Own	2,821	8,467,822	2.96
	Lease	69	194,984	0.07
	<b>Total</b>	<b>2,890</b>	<b>8,662,806</b>	<b>\$3.00<sup>b</sup></b>
Medium: 11-30%g Peak Ground Acceleration	Own	5,280	64,215,398	22.48
	Lease	888	9,495,449	3.32
	<b>Total</b>	<b>6,168</b>	<b>73,710,847</b>	<b>\$26.00<sup>b</sup></b>
High: 31-175%g Peak Ground Acceleration	Own	14,167	131,178,132	45.91
	Lease	1,088	6,688,122	2.34
	<b>Total</b>	<b>15,255</b>	<b>137,866,254</b>	<b>\$48.00<sup>b</sup></b>
<b>Overall Total Dollar Value at Risk</b>				<b>\$77.00<sup>b</sup></b>

<sup>a</sup> Sources: Department of General Services, California Governor's Office of Emergency Services (Cal OES), California Geological Survey (CGS)

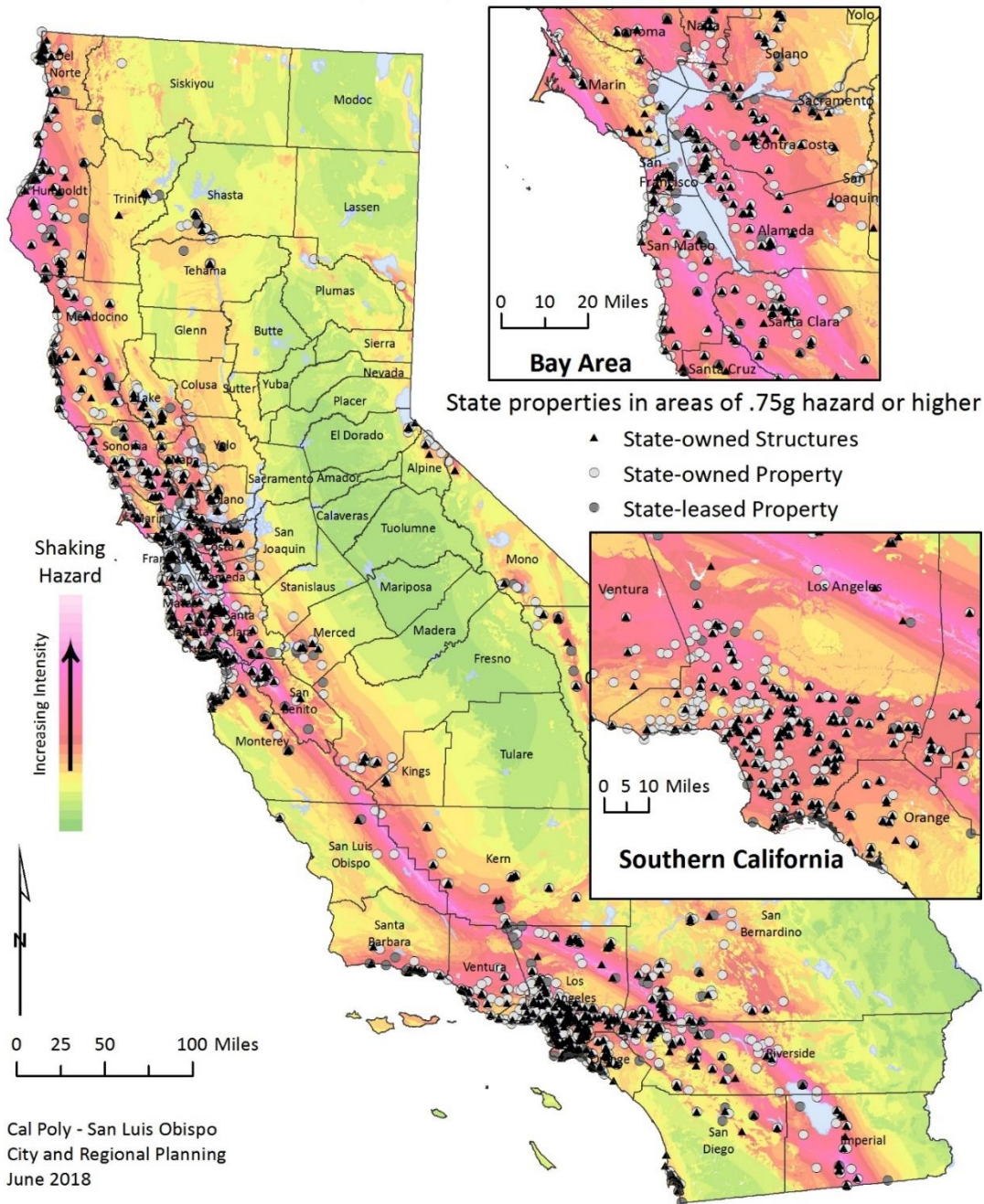
<sup>b</sup> number rounded

The Real Estate Division of the Department of General Services (DGS) maintains the State Property Inventory, which is a centralized real estate management information system. This database consists of a comprehensive inventory of all leased facilities reported to the Department of General Services and all state proprietary land holdings except for the California Department of Transportation (Caltrans) highway operating right of way and airspace. As agencies notify the DGS of changes, they are entered into the State Property Inventory. Maps created using these data show the physical location of real property as listed in the State Property Inventory, however the physical locations of structures owned by the state were determined using the address for each structure, and some of these addresses were not specific enough to place them on the map. (Please note that only properties "reported to the DGS" are included.)

This inventory includes structures with a wide range of vulnerability to earthquake risk. While some structures have been seismically upgraded under Proposition 122 (1990) bond funds and other funding sources, others remain vulnerable to damage and are in need of retrofitting.

The value of overall risk exposure to state-owned buildings from earthquake shaking hazards is noted in Table 6.D as roughly \$77 billion. This is far greater than the value of potential risk exposure of state owned buildings from flood and wildfire hazards, which are on the order of approximately \$2.0 billion each (see Tables 7.B and 8.D). Therefore, the seismic vulnerability of state-owned buildings is of great concern to the state.

**Map 6.M: State-Owned Structures and State-Owned and Leased Property in Earthquake Hazard Areas**  
**State-Owned Structures and State-Owned and -Leased Property in Earthquake Hazard Areas**



Source: Earthquake Shaking Potential (rev. 9/30/16) is from Department of Conservation, California Geological Survey, and is protected by the United States Copyright Law. For more information, contact the California Department of Conservation, California Geological Survey.  
 State Property Inventory data from California Dept. of General Services, March 2017.

Created by: C. Schuldt (6.L--State Property and Earthquake Hazard.mxd)

Map 6.M shows the location of state-owned buildings and state-owned and -leased properties in potential strong ground shaking areas that are listed in the State Property Inventory.<sup>100</sup> Large concentrations are found in Southern

<sup>100</sup> 1.0 second spectral acceleration with 2-percent probability of exceedance in 50 years.

California and the San Francisco Bay Area. At a statewide scale, it is difficult to differentiate individual locations of every state structure or property; however, this map's primary purpose is to illustrate the large concentrations of state structures and properties located in areas of stronger intensity shaking hazard.

### **Vulnerabilities of State Inventory**

The following building types, representing a mix of structural type and function, are discussed in this subsection:

1. State Critical Services Buildings
2. Other State-Owned Normal Occupancy Facilities
3. State Criminal Justice Buildings
4. State-Owned Health Services Facilities
5. Public Universities
6. Community Colleges

Cutting across all sub-inventories of vulnerable buildings by function and type are the state-owned and -leased buildings. There are over 25,000 state-owned structures, including over 5,000 university buildings. In addition, there are 2,300 state-leased buildings, with lease terms varying in length. This section discusses the numbers, distribution, square footage, and value of state-owned and -leased properties in high earthquake hazard areas. [Section 6.1.5.2](#) discusses specific mitigation efforts underway for the inventory types listed below.

#### *1. State Critical Services Facilities*

California has no statewide inventory of state critical services facilities, including fire, police, ambulance, and emergency communication facilities. Most of these facilities were built before state standards were adopted governing the design and construction of essential services structures. Therefore, they are not expected to be reliably functional after earthquakes, delaying emergency response and in some cases posing significant risks to life. Key state agencies owning essential services facilities include:

- The California Department of Forestry and Fire Protection (CAL FIRE)
- Caltrans
- The California Highway Patrol (CHP)
- The Department of Water Resources (DWR)
- California Governor's Office of Emergency Services (Cal OES)

#### *2. Other State-Owned Normal Occupancy Facilities*

California has an asset management program for non-university buildings that maintains an inventory of over 25,000 buildings with a total of almost 240 million square feet of space.

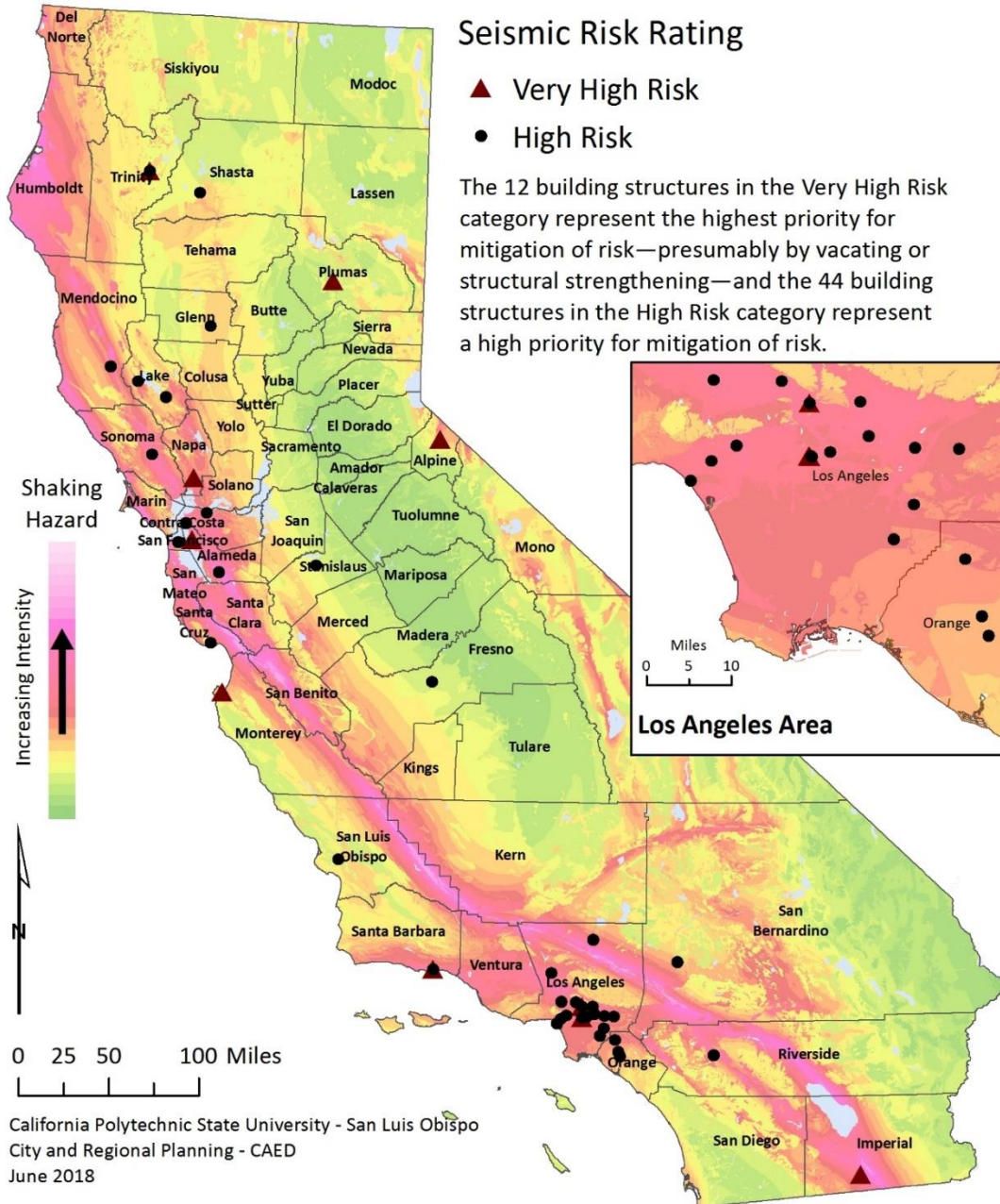
#### *3. State Criminal Justice and Judicial Court Buildings*

A 1979-1980 renovation and planning study funded by the Department of Corrections included seismic evaluations and identification of remedial actions for major state prison buildings. In March 2017, a Seismic Risk Rating Study of California Superior Court Buildings report was published by the Judicial Council Program. This study updated results of a seismic assessment program initiated in 2003, updating building inventory, and enhancing the functionality of the 2003 seismic risk ratings database.

As part of the 2017 study, a Seismic Risk Assessment tool was developed to evaluate risk and prioritize future mitigation for the 145 judicial structures identified as Risk Level V (risk of collapse or major risk to life). The assessment tool uses FEMA's HAZUS modeling algorithm.

Map 6.N: Court Buildings Vulnerable to Earthquakes

# Very High and High Seismic Risk for Superior Court Buildings



Map 6.N shows locations of court buildings determined by the assessment to be at high or very high risk in relation to shaking hazard potential throughout the state. To review the assessment report, visit: <http://www.courts.ca.gov/documents/Seismic-Risk-Rating-of-California-Superior-Court-Buildings.pdf>.

#### 4. *State-Owned Health Services Facilities*

The State of California manages seismic risk in its health care facilities through the Department of General Services (DGS), California Department of Health Care Services, and California Department of Developmental Services. The state owns:

- Five mental health hospitals with over 6 million square feet of space
- Three developmental centers with 3.5 million square feet of space
- Two public health laboratories

#### 5. *Public Universities*

The University of California (UC) and California State University (CSU) systems together have 192 primary and satellite campuses and 10,000 buildings with 138 million square feet of space. Since the early 1970s, UC has been evaluating and retrofitting buildings on its campuses. The system has ranked the seismic safety of its major buildings from “good” to “very poor” (known as III to VI in the 2017 updated version of UC’s seismic safety policy) and has embarked on capital outlay programs to retrofit those that are ranked “poor” (or V in accordance with the updated policy) or “very poor” (or VI in accordance with the updated policy). In the early 1990s, CSU initiated a similar program.

#### 6. *Community Colleges*

In 2000, the community colleges chancellor’s office funded a rapid seismic evaluation of buildings constructed to early Field Act standards. The survey found that the community college system has 20 district offices, 108 campuses, 54 off-campus centers, 4,366 buildings overall, and 52.2 million square feet of space. Of the total buildings, 1,600 were given a rapid seismic evaluation to identify retrofit needs that are now integrated into future capital outlay plans.

### **California Vital Infrastructure Vulnerability Assessment (Cal VIVA)**

The California Vital Infrastructure Vulnerability Assessment (Cal VIVA) was begun during preparation of the 2010 SHMP. Its purpose was to develop and test a methodology for assessing the seismic vulnerability of state-owned building stock and critical infrastructure to seismic and other hazards and determine minimum retrofit measures to protect its occupants from harm during a disaster and facilitate recovery by making it quickly operable after a disaster.

The vision for Cal VIVA was to 1) create an infrastructure resiliency planning and evaluation system that includes the long-term systematic screening of the state-owned building inventory, 2) determine potential vulnerabilities within that inventory, 3) systematically plan and set priorities for vulnerable building strengthening, and 4) execute initial building retrofit assessments, subject to project funding, design, and development.

The original Cal VIVA efforts focused on establishing methods for assessing seismic vulnerability of state-owned buildings and recommending retrofit actions. The screening approach/methodology was tested on 19 buildings from four departments: Department of Forestry and Fire Protection (CAL FIRE), California Highway Patrol (CHP), California Department of Transportation (Caltrans), and California Department of Water Resources (DWR). For these selected facilities, the project made recommendations and developed associated costs for mitigating structural and non-structural seismic vulnerabilities should funding become available. There is, however, a remaining gap to identify state-owned or -operated critical facilities and to consider California’s highest risk hazards that are also subject to impacts of climate change.

### Progress Summary 6.B: Cal VIVA III and the Climate Adaptation Strategy Project 6A

**Progress as of 2018:** Three increments of the California Vital Infrastructure Vulnerability Assessment (Cal VIVA) have been initiated and completed. Final reports for the first and second projects Cal VIVA I and II were completed in March 2013. Cal VIVA I had three primary activities: 1) develop a standardized methodology to identify necessary mitigations of seismic vulnerabilities in buildings that are critical to response and recovery efforts after an earthquake, 2) test the methodology and 3) improve the methodology based on lessons learned.

Cal VIVA II, the second project used the seismic vulnerability assessment methodology developed in Cal VIVA I to examine two areas: 1) the conceptual development of a prototypical department plan for mitigation of seismic vulnerabilities in critical state-owned buildings, and 2) determination of the seismic vulnerability with resultant mitigation of selected state-owned, high-occupancy office buildings housing state employees critically needed for post-earthquake response and recovery operations.

The third project, Cal VIVA III, prepared in association with the Earthquake Engineering Research Institute (EERI), was completed in November 2013. Cal VIVA III tested and refined the Cal VIVA II prototypical department plan with an individual user department and produced a template that can be used by departments and agencies within state government to systematically address critical building vulnerability and potential retrofits on a long-term basis.

Since 2015, portions of the Cal VIVA project assessment model have been used as the basis for a new project from the Fourth Climate Change Assessment called “*Assessing Vulnerability and Improving Resilience of Critical Emergency Management Infrastructure in a Changing Climate*,” also known as “Project 6A.” Project 6A seeks to establish and implement an ongoing system to prioritize projects in relation to their relative importance to the continuity of state government and recovery operations following a natural disaster, with particular emphasis on providing resilience to disadvantaged communities. Whereas Cal VIVA was a system to assess seismic integrity of state owned buildings, it did not address other climate change variables nor did it establish a way to set budget priorities or how to choose the importance of the infrastructure to state needs after a disaster event. This project pulls from and fills some of the gaps in the Cal VIVA effort, by providing data related to the risk scores for assets and critical infrastructure systems, and their operators.

## 6.1.4 ASSESSMENT OF LOCAL EARTHQUAKE VULNERABILITY AND POTENTIAL LOSSES

This section addresses local earthquake hazard vulnerability and potential losses based on estimates provided in local risk assessments, comparing those with findings of the state risk exposure findings presented in the GIS analysis in [Section 4.4.4](#) of [Chapter 4: Profiling California’s Setting](#).

### 6.1.4.1 EARTHQUAKE VULNERABILITY OF BUILDINGS

This section discusses statewide and local vulnerability of buildings susceptible to earthquake damage, the greatest single factor contributing to California’s potential future losses from earthquakes. It provides an overview of building vulnerability and potential structural losses from fires following earthquakes. It then reviews vulnerability with respect to a series of building sub-inventories, including private structures as well as state-owned and -leased buildings. The section is organized to provide the link between vulnerabilities of key building inventories by function and structural type. Mitigation progress for the building inventories described below is discussed in [Section 6.1.5.2](#).

#### Building Vulnerability to Earthquake Damage

Compared to other earthquake vulnerabilities, buildings pose the largest risk to life, injury, property, and economic welfare. California has approximately 14 million buildings, with an average of 2.7 occupants per building. Approximately 95 percent are low-rise (one to three stories), 5 percent are medium-rise (four to seven stories), and 0.03 percent are high-rise buildings (eight or more stories).<sup>101</sup> Observations after earthquakes indicate that building

<sup>101</sup> Jones, et al. ATC 13.

safety is most often compromised by poor quality in design and construction, inadequate maintenance, lack of code enforcement at the time of original construction, and improper alterations to the original building.<sup>102</sup>

A less common cause of damage is the poor performance of older buildings built to earlier seismic codes. Approximately 13 percent of California’s buildings were constructed before 1933, when explicit requirements for earthquakes first began to be incorporated into building codes and the state first required local governments to create building departments and issue permits.

About 18 percent of California’s buildings were constructed before 1940, when the first significant strong motion recording was made in El Centro. About 40 percent of the state’s buildings were constructed before the Structural Engineers Association of California’s first statewide consensus on recommended earthquake provisions were published in 1960. About 60 percent were built before the mid- to late-1970s, when significant improvements to lateral force requirements began to be enforced throughout the state. California did not have uniform adoption of the same edition of model codes in every jurisdiction until the early 1990s. Thus, well over half of all existing buildings in California are built to earlier standards that, in many cases, can result in inadequate earthquake performance.

Nonstructural building components can also become vulnerable to damage during earthquakes. Ceilings, air conditioning equipment, plumbing and water heaters, windows, chimneys, appliances, and stone veneer are examples of non-structural components that may become damaged as a result of earthquake ground shaking.

### **Vulnerabilities by Building Sub-Inventories**

The following building types, representing a mix of structural type and function, are discussed in this section:

1. Locally Regulated Critical Services Facilities
2. Local Kindergarten through 12th Grade (K-12) Public Schools
3. Hospitals
4. Steel-Frame Buildings
5. High-Rise Buildings
6. Locally Regulated Non-Ductile Concrete Buildings
7. Locally Regulated Unreinforced Masonry (URM) Buildings
8. Tilt-Up Buildings
9. “Soft-Story” Buildings
10. Multi-Unit Wood-Frame Residential Buildings
11. Single-Family Wood-Frame Dwellings
12. Mobile/Manufactured Homes

---

<sup>102</sup> California Seismic Safety Commission, “Turning Loss to Gain,” CSSC 95-01.

**2014 South Napa Earthquake, Non-Structural Damage: Chimney Collapse**

Source: Janiele Maffei, California Earthquake Authority

Among the more vulnerable structures susceptible to potential loss in earthquakes are 25,945 unreinforced masonry (URM) buildings in high seismicity regions (as of 2006, 70 percent retrofitted or replaced), and approximately 4,000 URM buildings in moderate seismicity regions, as well as approximately 57,000 tilt-up buildings, over 20,000 non-ductile concrete structures,<sup>103</sup> 46,000 soft-story apartments, 1.5 million vulnerable single-family dwellings, and approximately 560,000 mobile homes,<sup>104</sup> in varying stages of retrofit.

### 1. Locally Regulated Critical Services Facilities

California has no statewide inventory of locally regulated essential services facilities, including fire, police, ambulance, and emergency communication facilities. Most of these facilities were built prior to 1986, before state standards began to require enhanced seismic safety, and are not expected to be reliably functional after severe earthquakes, delaying emergency response and in some cases posing significant risks to life. The Department of General Services (DGS) estimates there are approximately 900 fire stations, 400 emergency operations centers, and 450 police stations throughout California.

<sup>103</sup> Comartin et. al., 2011. Retrieved on April 25, 2018 from <http://www.concretecoalition.org/>

<sup>104</sup> Understanding the Seismic Vulnerability of Manufactured Homes Report, AIR, October 23, 2017. Retrieved on April 25, 2018. <http://www.air-worldwide.com/Publications/AIR-Currents/2017/Understanding-the-Seismic-Vulnerability-of-Manufactured-Homes/>

## 2. *Local K-12 Public Schools*

The California Department of Education reports there are over 10,000 public schools in California. Since 1933, public schools have been constructed in accordance with the Field Act, which requires thorough reviews of construction plans, strict inspections, and quality control by the Division of the State Architect (DSA). By 1977, nearly all public schools that were built before the Field Act had either been retrofitted or were no longer being used for instructional purposes.

The Field Act did not begin to regulate non-structural systems and building contents in schools until the 1970s. Many schools, particularly older public schools, contain falling hazards that can injure occupants. Assembly Bill 300, enacted in 1999, required DGS to survey all the public school buildings (K-12) in the state for seismic safety issues.

## 3. *Hospitals*

Since 1973, hospitals have been required to be built to higher standards than other buildings so they can be reoccupied after major earthquakes. However, most hospitals built before 1973 still remain in service, and some of them pose risks to life or are not expected to be available for occupation after future earthquakes. The 1973 Alquist Hospital Facilities Seismic Safety Act (HFSSA) designated the Office of Statewide Health Planning and Development (OSHPD) as the enforcement agency of the HFSSA mandates. OSHPD's primary objective is to safeguard the public health, safety, and general welfare through regulation of the design and construction of healthcare facilities, to ensure they are capable of providing sustained services to the public.

## 4. *Steel-Frame Buildings*

A welded steel moment-frame building is an assembly of beams and columns, rigidly joined together to resist both vertical and lateral forces. The buildings are designed to rely on these connections between beams and columns to resist ground movements caused by earthquakes. Until the 1994 Northridge Earthquake, this type of construction was considered an effective seismic-resistant structural system. At the time of the Northridge Earthquake, there were about 2,000 welded steel-frame buildings in Los Angeles. The city required an inspection of nearly 200 buildings in areas that experienced the most intense ground shaking; about 30 of those buildings sustained significant damage.

A FEMA study found that the damage sustained by steel-frame buildings was the result of a number of factors, including construction defects such as welds that were not bonded well with steel columns, changes in material properties of weld metal and structural steel, and a prescriptive design spelled out in building codes whose connection configurations became problematic and unreliable when used with large beams and columns. (For additional study details go to: <https://www.fema.gov/news-release/2001/04/18/study-earthquake-proof-steel-frame-high-rises-concluded-fema-issues-new>.) Elsewhere in the state no surveys of such buildings exist, although several similarly damaged buildings were discovered in the Bay Area years after the 1989 Loma Prieta Earthquake. An article published in the April 2017 issue of the Journal of the International Association for Earthquake Engineering estimated that the expected annual losses from earthquakes on steel moment frame buildings varies from 0.38 percent to 0.74 percent over the building life expectancy.

## 5. *High-Rise Buildings*

There is no statewide inventory of high-rise buildings. Only approximately 0.03 percent of all buildings in the state have eight or more stories. However, much of California's corporate, finance, legal, and insurance commerce takes place in these buildings. The potential for loss of market share in the economy from the closure of these buildings after earthquakes due to non-structural damage is significant. The Council on Tall Buildings and Urban Habitat maintains an inventory of high-rise buildings at: [www.ctbuh.org](http://www.ctbuh.org).

### 6. Locally Regulated Non-Ductile Concrete Buildings

There is no statewide inventory of concrete buildings. However, the Concrete Coalition estimated in 2011, that there are approximately 20,000 to 23,000 non-ductile concrete buildings within California, including residential, commercial, school, and critical services buildings, of which 16,000 to 17,000 are in high seismicity areas.<sup>105</sup> According to the Concrete Coalition, the City of Los Angeles alone has over 1,500 older concrete buildings and San Francisco has an estimated 3,000 older concrete buildings.

These buildings, particularly older ones with high numbers of occupants, can collapse and kill hundreds. This type of building is the fastest-growing cause of earthquake losses around the world.<sup>106</sup> California instituted changes in building codes in the mid-1970s that were intended to stem losses in newer buildings constructed to later standards. However, the great majority of these buildings constructed before the mid-1970s have not been evaluated or retrofitted.

Two specific types of non-ductile concrete construction are flat slabs and lift slabs. With lift slab construction, concrete slabs are cast on the ground, lifted into place, and then connected to columns. Flat slabs are cast-in-place, and connect to columns without beams. Historically, both types of construction were often designed without adequately accounting for the full movement a building will experience during an earthquake and older such buildings can therefore be prone to slab failure during a large earthquake.

### 7. Locally Regulated Unreinforced Masonry Buildings

Unreinforced masonry (URM) buildings are made of brick, stone, or other types of masonry and have no reinforcing steel to keep them from collapsing or partially collapsing in earthquakes. Most URM buildings have features that can threaten lives during earthquakes. These include parapets, walls, and roofs that are poorly connected to each other. When earthquakes occur, inadequate connections in these buildings can allow masonry to fall, placing occupants and passersby in harm's way. Floors and roofs can also collapse.

The risk to life from URM buildings can be significantly reduced by the regulation of alterations to existing buildings and seismic retrofits. California has prohibited the construction of new URM buildings since 1933. However, many URM buildings still remain in use today in California's older commercial and industrial districts in high seismic hazard regions.

### 8. Tilt-Up Buildings

Tilt-up buildings are typically one- or two-story buildings constructed of concrete walls that are poured horizontally, tilted into vertical positions, and connected to each other and to roofs. If the connections between the walls and roofs are weak, the walls can pull away from roofs and collapse during ground shaking.

There is no statewide inventory of tilt-up buildings. However, a 1991 estimate suggested that there were approximately 57,000 throughout the state.<sup>107</sup> Forty percent of these were built prior to 1976, after which building codes began to require stronger wall-to-roof connections. Many tilt-up buildings have been constructed in the past decade, generally to more current construction standards. Additional enhancements to the building code for new tilt-up construction were adopted in 1997.

<sup>105</sup> Comartin, C., Bonowitz, D., Greene, M., McCormick, D., May, P., Seymour, E. (2011). The Concrete Coalition and the California Inventory Project: An Estimate of the number of Pre-1980 Concrete Buildings in the State. Final Draft. August. Oakland, CA: The Earthquake Engineering Research Institute.

<sup>106</sup> Coburn, 2002

<sup>107</sup> EQE, 1991

### 2014 South Napa Earthquake, Unreinforced Masonry Wall Collapse



Source: Janiele Maffei, California Earthquake Authority

#### 9. “Soft-Story” Buildings

Multi-unit residential structures with soft, weak, or open fronts are commonly referred to as “soft-story” buildings. Soft-story residential buildings are multi-story wood-frame structures with inadequately braced lower stories that may not be able to resist earthquake motion.

Soft-story buildings are an important component of the state's housing stock and are in jeopardy of being lost in the event of severe shaking. For example, the Association of Bay Area Governments (ABAG) has estimated that soft-story residential buildings will be responsible for 66 percent of the uninhabitable housing following an earthquake on the Hayward Fault. The failure of soft-story residential buildings is estimated by ABAG to be the source of a disproportionate share of the public shelter population because such structures tend to be occupied by the very poor, very old, and very young.

#### 10. Multi-Unit Wood-Frame Residential Buildings

There is no statewide inventory of multi-unit wood-frame residential buildings. However, the approximate number of buildings can be inferred from local inventories available from select cities as summarized below. A significant number (perhaps one-third) of all apartments and condominiums have parking at the lower levels, which can create earthquake vulnerabilities. These buildings can collapse and cause casualties and property loss and be rendered uninhabitable after earthquakes. Up to 84 percent of the loss of housing in a Hayward Fault earthquake scenario is expected to occur in multi-family residential buildings.<sup>108</sup>

<sup>108</sup> ABAG, 1999

### *11. Single-Family Wood-Frame Dwellings*

Approximately 1.5 million single-family dwellings were built in California before 1960, when jurisdictions began to require adequately braced walls. Homes can slide or fall off their foundations if not adequately anchored and braced.

The primary risk posed by single-family wood-frame buildings is the potential for loss of housing and property after earthquakes. In addition, poorly braced homes on steep hillsides can slide down hills and present significant threats to life. Falling chimneys can also cause casualties and damage.

### *12. Mobile/Manufactured Homes*

California has approximately 393,000 mobile/manufactured homes within mobile home parks. The Department of Housing and Community Development (HCD) regulates mobile/manufactured home installations in approximately 3,648 of the state's 4,556 mobile home parks and inspects alterations to all state mobile/manufactured homes. Local governments have enforcement jurisdiction over 908 mobile/manufactured home parks, as well as mobile/manufactured home installations outside of parks.

In 1994, HCD began to require engineered tie-down devices during mobile/manufactured home installations to resist wind loads of 15 pounds per square foot or the design wind load of the homes, whichever is greater. However, most homes installed prior to 1994 are not attached to engineered tie-down systems to resist horizontal loads.

Homes on inadequate foundations can shift and fall several feet in earthquakes, severing gas lines. During the Northridge Earthquake, approximately 95 percent of unbraced mobile homes fell off their foundations. Risk of fire during an earthquake event is also increased as a result of broken gas connection lines when mobile homes collapse or shift off their foundations. Doors can become stuck, trapping occupants and creating serious threats to life in events with fires.<sup>109</sup>

## **Fires Following Earthquake**

While ground shaking may be the predominant agent of damage in most earthquakes, fires following earthquakes can also lead to catastrophic damage depending on the combination of building characteristics and density, meteorological conditions, and other factors. Fires following the 1906 San Francisco Earthquake, 1923 Tokyo Earthquake, and 1995 Kobe Earthquake caused extensive damage and killed thousands.

Fires following the 1906 San Francisco Earthquake led to more damage than was caused by ground shaking. Most recently, fires in the Marina District of San Francisco following the 1989 Loma Prieta Earthquake and in Los Angeles following the 1994 Northridge Earthquake demonstrate that fires following earthquakes pose a significant hazard, especially in densely populated urban areas, and a potentially serious problem due to severe strain on the fire departments that must respond to multiple simultaneous ignitions. Fire department response is often affected by impaired communications, water supply, and transportation, together with other emergency demands such as structural collapses, hazardous materials releases, and emergency medical aid.

Fires following earthquakes may result from multiple causes (e.g., overturned burning candles, electrical sparking from downed power lines, and broken natural gas pipelines<sup>110</sup>). Numerous instances of serious fires following earthquakes have occurred in major urban areas. Fires following earthquakes can occur immediately after an earthquake or may be delayed. Causes of fires occurring immediately after include power lines that are fused or broken, with the resulting arcing coming into contact with combustible fuel; water heaters, stoves, and lighting fixtures/lamps that are dislodged and come into contact with combustible fuel; natural gas mains, lines, and service that are severed, with the released gas finding a source of ignition; and combustible liquids that leak and find a source of ignition.

<sup>109</sup> SSC 95-01, Turning Loss to Gain

<sup>110</sup> A complete list may be found in *Fire Following Earthquake*, Edited by Charles Scawthorn, John Eiding, and Anshel Schiff. Technical Council on Lifeline Earthquake Engineering, Monograph No. 26. Published by the American Society of Civil Engineers. January 2005.

Fires that are delayed are generally human-caused or preventable (for example, fire caused by the restoration of electricity to an area not properly checked and secured). When power is restored, heating of electrical appliances can occur followed by ignition. Inexperienced people can start fires by trying to relight gas pilots. Vulnerability to fires following earthquake can be assessed for communities by well-established simulation models.

Several computer programs (e.g., HAZUS, EQEFIRE, URAMP, SERA, and RiskLink) are available to assess the fire-following-earthquake vulnerability of a community in future earthquakes. Details of various computer-modeling techniques are described in the book *Fire Following Earthquake*.<sup>111</sup>

#### **6.1.4.2 EARTHQUAKE VULNERABILITY OF LIFELINE INFRASTRUCTURE**

California's lifeline infrastructure is extensive and complex. Lifeline infrastructure is any continuously engineered system providing transportation, communication, water, power or other distributed utility services.

There is no comprehensive database for seismic hazard assessment or mitigation for lifelines as a group or for particular types of lifelines. However, various groups have collected data on the performance of utilities and transportation systems during and after earthquakes in California and elsewhere. The data collection and analysis effort has been applied on an irregular basis to various utility components. This is primarily due to the fact that a great deal of California's lifeline infrastructure has been in existence since before the 1971 San Fernando Earthquake. As new standards and guidelines have been developed, lifeline providers have been using new data and design techniques to assess seismic hazards for power plants, electrical transmission and distribution systems, natural gas pipelines, water supply lines (including canals and aqueducts), and dams for new projects and seismic retrofit projects. Caltrans and local governments have also been retrofitting bridges using new design techniques and new standards and guidelines.

Data regarding locally owned transportation retrofit activities are not monitored in California. However, several facilities and utility providers are known to have taken action for seismic hazard mitigation. These facilities include ports and airports, and utility providers include the Port of Los Angeles, East Bay Municipal Utility District (EBMUD), Pacific Gas & Electric, and Bay Area Rapid Transit.

Experience gained after assessing earthquake performance of utilities and transportation systems points to the following:

1. Various degrees of damage affect the functionality of utilities, roads, bridges, ports, or airports. The extent of damage is related to the severity of the seismic hazard at the facilities in question, quality of the soils or rock at and adjacent to the site, design criteria used in building the facilities, and age and condition of the facilities. Those facilities of high-quality construction and built on good soil or rock tend to perform better than those built on poor soils.
2. Typical design standards for utilities and transportation systems focus on preventing the loss of lives and reducing property damage but do not guarantee that the facility will remain functional after an earthquake.
3. Fault rupture and seismic-induced landslides have caused breakage of pipes and offsets in the foundations of electrical power towers, roads, and buildings.

---

<sup>111</sup> Scawthorn, et al. January 2005.

Observations of damage from California earthquakes have also shown that ground shaking may be locally attenuated but then be amplified farther away due to differential soil conditions and structural response. Such was the case in the 1999 Hector Mine Earthquake when an oil storage tank near Wilmington (over 100 miles from the epicenter) was damaged while minimal or no damage was observed in cities between the epicenter and the tank. Ground shaking may also damage aboveground pipelines and their support framing in a similar manner.

This section discusses the following:

1. Electrical utilities
2. Pipeline networks: oil and natural gas
3. Petrochemical facilities: oil refineries and liquefied natural gas facilities
4. Localized water and wastewater pipelines and treatment facilities
5. Statewide water system: aqueducts, canals, levees, dams, and reservoirs
6. Solid waste disposal systems
7. Transportation systems
8. Ports and harbors
9. Communication systems

For additional information regarding lifeline systems, see [Annex 3](#) of this document.

### *1. Electrical Utilities*

California has 31,721 miles of electric transmission lines and up to double that amount in the electric distribution system. In addition, California has 188 operational power plants varying in size from 50 megawatts to over 2,000 megawatts, generating a total of up to 53,700 megawatts. California also imports, to various degrees throughout the year, electric power from outside of the state. Several assessments of electric power generation, transmission, and distribution systems have been performed following California earthquakes as well as earthquakes in Japan and elsewhere. See Map 6.O for an overview of the state electrical grid.

#### *Vulnerabilities*

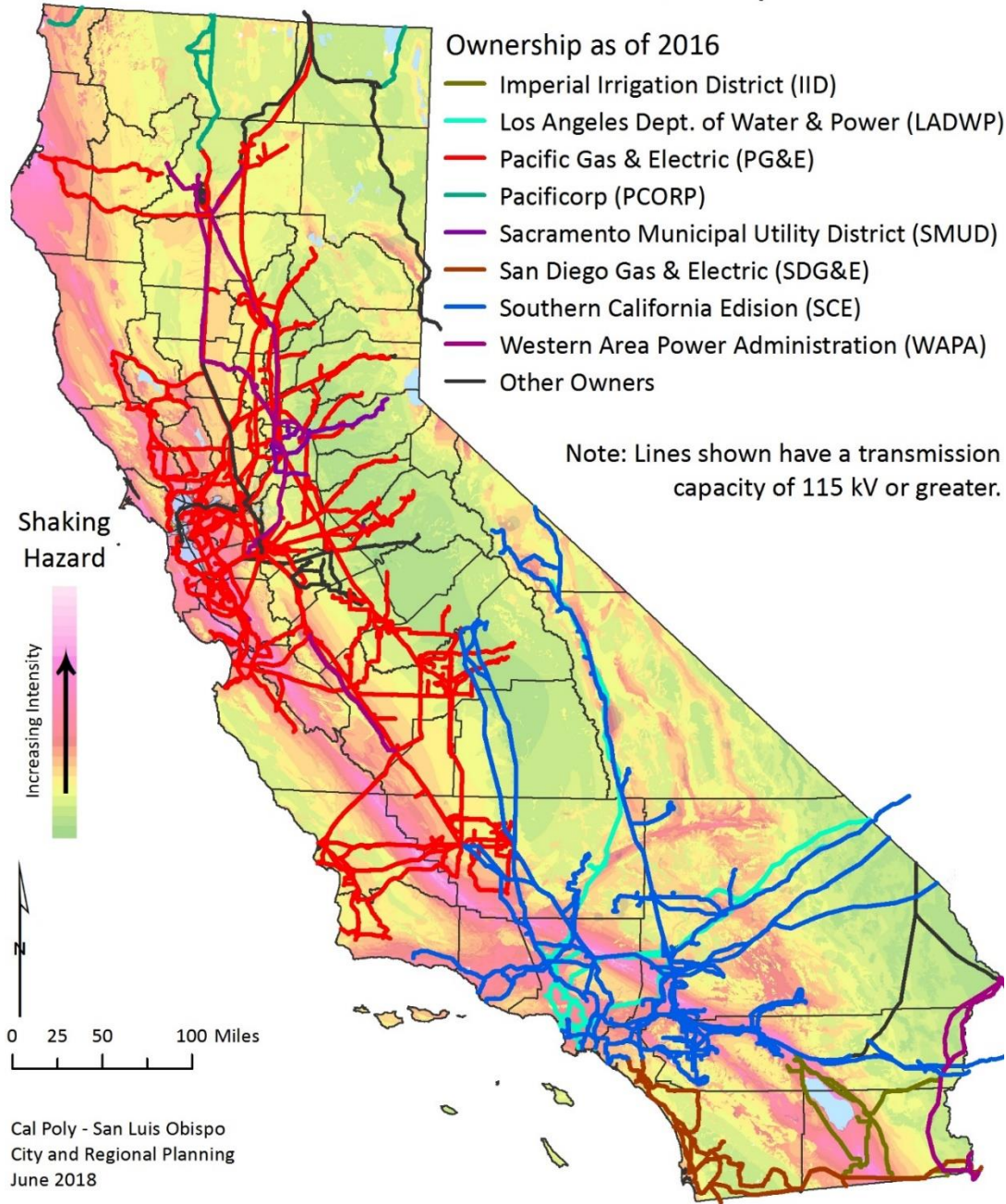
No statewide, comprehensive seismic hazard vulnerability inventory for electrical power generation, transmission, and distribution exists in California. However, some individual electric utilities have assessed their system vulnerability with respect to seismic hazard. Additionally, through HAZUS and other earthquake planning scenarios developed for Northern and Southern California, potential vulnerability has been identified. See [Section 6.1.3.1](#) for more information.

The greatest vulnerability is from strong ground shaking. High-voltage sub-stations or switchyards are particularly vulnerable for two reasons: 1) sub-stations and switchyards tend to be key facilities in the ability of a distribution or transmission system to reroute power around or to areas affected by earthquakes, and 2) some high-voltage sub-station and switchyard equipment is relatively brittle.

The amounts of recorded sub-station and switchyard damage after the 1971 San Fernando Earthquake, 1986 Palm Springs Earthquake, and 1994 Northridge Earthquake highlight these two vulnerabilities. The ground motion hazard is generally the greatest hazard overall. In regions struck by earthquakes, it is likely that vulnerable electric power equipment is in the area of strong ground shaking. Earthquake shaking can cause electrical lines to slap together, causing the lines to catch fire. Shaking can also result in dynamic response of transformers and other structural components, resulting in damage and loss of transmission.

Map 6.O: Electric Transmission Lines and Earthquake Hazard

# California Electric Transmission Lines and Earthquake Hazard



Source: Earthquake Shaking Potential (rev. 9/30/16) is from Department of Conservation, California Geological Survey, and is protected by the United States Copyright Law. For more information, contact the California Department of Conservation, California Geological Survey.  
California Energy Commission  
Cal-Atlas

Created by: C. Schuldt (6.N--Electric Transmission Lines and Shaking Intensity.mxd)

As shown in Map 6.O, the highest concentration of electrical transmission lines in both Northern and Southern California are in areas at risk from high shaking intensity.

In California, significant seismic hazard mitigation research has been conducted by electric utilities and researchers through organizations such as the Pacific Earthquake Engineering Research Center. Mitigation research products and results are making their way into new construction, purchasing, and siting decisions for all aspects of the electric utility industry in California.

Other vulnerable aspects of electrical transmission distribution and generation facilities include:

- Landslides that can damage electric transmission or distribution towers, substations, or switchyards.
- Ground deformation such as subsidence or lateral spreading from liquefaction that can cause a misalignment in the power train of an electric power plant. Typically, such problems can be mitigated by careful assessment of the potential for on-site liquefaction and the proper design of foundations.

#### *Interdependency on Electric Power*

A key aspect of vulnerability is the potential for loss of electrical power in:

- Natural gas pipelines, including compressor and pumping stations
- Oil transmission pipelines and pumping stations
- Oil, natural gas, or water storage facilities
- Water supply systems and pumping stations
- Wastewater treatment and disposal systems

All of these systems rely on electric power; so when power is disrupted the services are interrupted. In some cases, automatic shut-off valves and emergency power systems such as diesel generators have reduced this risk. Ground waves move at the speed of sound while electronic signals travel at the speed of light providing an opportunity for smart valve intervention.

## *2. Pipeline Networks: Oil and Natural Gas*

California is reported to have 12,414 miles of natural gas transmission pipeline (see [Section 9.2.3](#)) and for more information on California's natural gas pipelines). No comprehensive statewide seismic hazard vulnerability inventory for pipeline networks exists in California. However, several regional utilities have assessed their natural gas pipe works with respect to seismic hazard. Municipalities, special jurisdictions, and the state also own pipelines. Additionally, through HAZUS and other earthquake planning scenarios developed for Northern and Southern California, potential vulnerability has been identified.

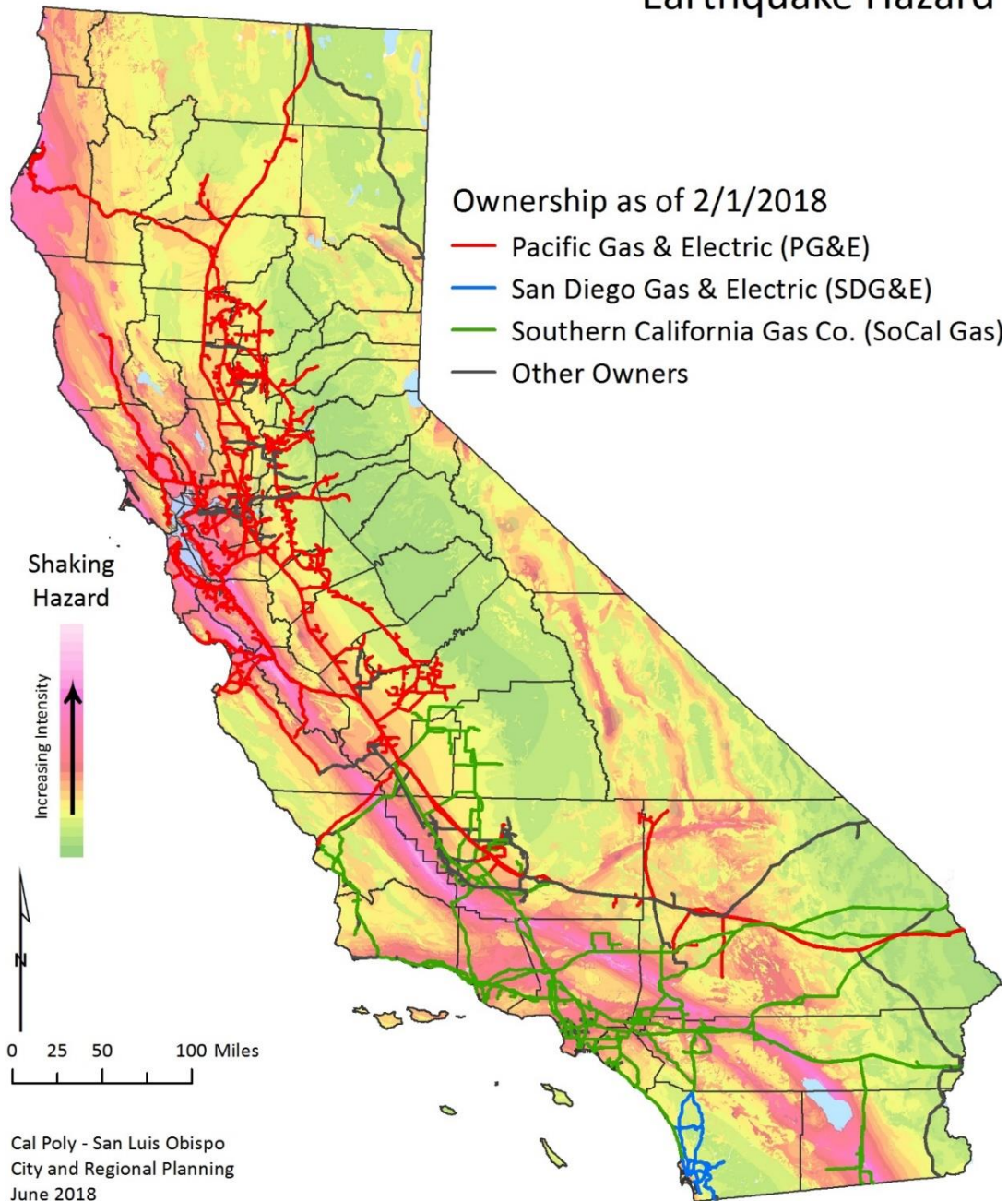
A significant contributor to pipeline failure after an earthquake is liquefaction. When soil liquefies it can lose shear strength or shear resistance, essentially becoming a fluid with the density of soil. If a pipeline or any other underground structure has a density less than the liquefied soil, it is then subjected to buoyant forces and thrust to the surface. This happens with underground pipes, tanks, and other low-density structural and non-structural components. In the larger view, severe disruptive impacts of a catastrophic earthquake could occur in California due to inadequate design and/or deteriorating conditions of aging gas transmission pipelines.

The recent earthquakes around Christchurch, New Zealand, have provided useful data on pipe performance. O'Rourke et al (2014) found that high-density polyethylene used for gas mains handled large ground deformations with the least amount of loss of service when compared to other pipe material types. Ongoing research has shown that this material can also sustain deformations from fault rupture, slides, and other large strain mechanisms.<sup>112</sup>

<sup>112</sup> Thomas D. O'Rourke, Sang-Soo Jeon, Selcuk Toprak, Misko Cubrinovski, Matthew Hughes, Sjoerd van Ballegooy, and Dimitra Bouziou (2014) Earthquake Response of Underground Pipeline Networks in Christchurch, NZ. *Earthquake Spectra*: February 2014, Vol. 30, No. 1, pp. 183-204.

Map 6.P: Natural Gas Pipelines and Earthquake Hazard

## California Natural Gas Pipelines and Earthquake Hazard



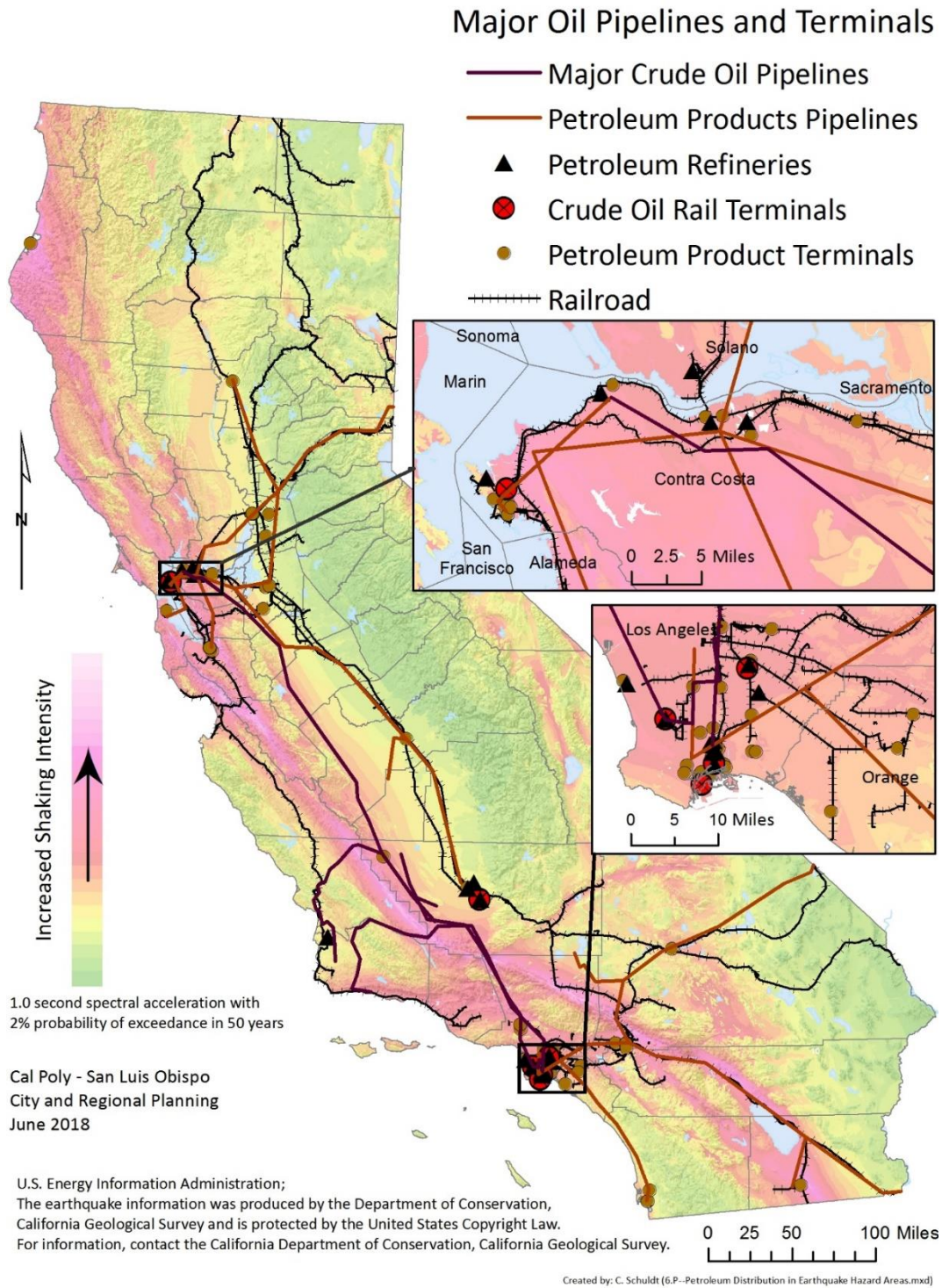
Source: Earthquake Shaking Potential (rev. 9/30/16) is from Department of Conservation, California Geological Survey, and is protected by the United States Copyright Law. For more information, contact the California Department of Conservation, California Geological Survey, California Energy Commission  
Cal-Atlas

Created by: C. Schuldt (6.0—Natural Gas Pipelines and Shaking Intensity.mxd)

Map 6.P shows that, as with electrical transmission lines (as shown in Map 6.O), the highest concentration of natural gas pipelines in both Northern and Southern California are in areas at risk from high shaking intensity.

### Map 6.Q: California's Petroleum Distribution System and Earthquake Hazard

## Petroleum Distribution in Earthquake Hazard Areas



Map 6.Q illustrates the location of the petroleum distribution system within California and the potential vulnerability to seismic shaking.

### 3. Petrochemical Facilities: Oil Refineries and Liquefied Natural Gas Facilities

California has major petrochemical facilities that include:

- Oil refineries
- Oil storage facilities
- Gasoline storage facilities
- Liquefied natural gas facilities
- Marine oil terminals

### 4. Localized Water and Wastewater Pipelines and Treatment Facilities

Water filtration plants and wastewater treatment facilities are often located in areas subject to severe ground shaking and liquefaction, flooding, or tsunami inundation. Damage to water filtration plants can result in disruptions of clean water supplies. Damage to wastewater treatment facilities or their intake pipe works or effluent disposal systems can result in immediate serious public health hazards. Loss of power can also lead to discharges of partially treated or untreated effluent into waterways or the ocean.

In addition to the potential hazards from damage to filtration systems, impacts on water quality, and infectious disease concerns, there is also a chance for chemical releases of disinfection products, such as chlorine, used in waste and other water treatment facilities to occur during a seismic event.

The epicenter of the 1994 Magnitude 6.7 Northridge Earthquake was near the middle of the San Fernando Valley in Los Angeles. Strong ground motion caused moderate damage to two wastewater treatment plants, one owned by the Los Angeles Department of Water and Power (LADWP) and the other by the Metropolitan Water District of Southern California. LADWP had approximately 1,000 pipeline failures including about 35 in transmission lines. Most of the failures occurred in cast iron pipe. About half of San Fernando Valley was without water, and restoring household service took nearly two weeks. Restoring full functionality took much longer.

In the larger view, severe disruptive impacts of a catastrophic earthquake could occur in California due to inadequate design and/or deteriorating conditions of aging water transmission pipelines and wastewater collection pipelines. This is especially true for Southern California, where much of the water supply is transported from long distances, through 900 miles of canals and tunnels. The 2008 Great ShakeOut scenario in Southern California identified fires and serious long-term disruptions to imported water delivery as potential consequences from severed gas and water transmission pipelines in a Magnitude 7.8 earthquake, particularly for pipelines crossing the San Andreas Fault. Scawthorn's 2003 Earthquake Engineering Handbook documented the need for greater attention in urban areas to potential fires following earthquakes and disruption of water supply for fire-fighting response where water systems are damaged or destroyed by earthquakes.<sup>113</sup>

It has been found that in recent seismic events that polyvinyl chloride (PVC) has outperformed other materials for gravity wastewater pipes. Polyethylene performed well for pressurized water main pipes and is recognized as having good seismically resilience properties.<sup>114</sup>

Map 6.R shows the proximity of Southern California water supply infrastructure to faults and risk of exposure to high shaking intensity. This infrastructure, along with dams and reservoirs throughout the state, are major sources of water supply. These sources are supplemented by a complex water delivery system that provides water directly to the user.

<sup>113</sup> Scawthorn, et al. January 2005.

<sup>114</sup> Bill Noell (2013) Seismic Performance of Plastic Pipe Systems in 2010/2011 Canterbury Earthquakes. <https://www.pdp.co.nz/wp-content/uploads/2018/04/2015-Noell-Seismic-performance-of-plastic-pipes-systems-in-2010-111.pdf>

The 2014 South Napa Earthquake highlighted the vulnerability of water and wastewater systems to earthquake-related ground failure, the additional fire hazards that earthquake-related water-system failures can pose, and the fiscal challenges that public agencies face in improving the seismic resiliency of these systems, both pre- and post-earthquake.<sup>115</sup>

In the 1989 Loma Prieta Earthquake, 90 percent of the water main breaks were due to liquefaction, primarily in the Marina District of San Francisco. The East Bay Municipal Utility District (EBMUD), which services Alameda and Contra Costa Counties, also suffered breakages that raised concerns about the vulnerability of its system. This spurred EBMUD to review its entire water distribution network, including the major transmission pipes critical to water delivery, 4,100 miles of distribution system pipes, 140 pumping plants, 170 neighborhood reservoirs (tanks storing treated drinking water), and five treatment plants.

Scenarios developed by FEMA to inform the preparation of the Bay Area Earthquake Plan (BAEP), using the HAZUS model, projected that, in response to a 7.0 Magnitude earthquake occurring on the Hayward Fault or a 7.8 Magnitude earthquake occurring on the San Andreas Fault, over 3.5 million residents would be without water, with 25 percent to 30 percent still not having water restored after 90 days.

##### *5. Statewide Water System: Aqueducts, Canals, Levees, Dams, and Reservoirs*

California uses over 1,200 dams and thousands of miles of levees to meet its water supply, conveyance, and flood protection demands. Although two-thirds of California's water supply generally originates in the northern third of the state, two-thirds of the population resides in the southern third. Southern California is heavily dependent upon water brought by the canals and tunnels comprising the Los Angeles Aqueduct, Colorado River Aqueduct, and State Water Project. The greatest weakness of this system is liquefaction-induced failures caused by strong ground shaking.<sup>116</sup>

Dams are a major component of this water collection and delivery system. Earthquake instrumentation of dams was begun after the 1971 Sylmar Earthquake, and though the effort continues with strong motion instrumentation projects conducted by the California Geological Survey (CGS) and Department of Water Resources (DWR), fewer than 45 dams have adequate instrumentation as of late 2017. Modern adequate instrumentation can provide the data to assist with rapid assessment of the health of a dam after significant earthquakes.

During the 1971 Sylmar Earthquake, the Lower San Fernando Dam, which is upstream from a heavily populated area, was severely damaged from liquefaction. Though heavily damaged, the dam was not breached and no dam failure-induced flooding occurred. The 1971 earthquake also initiated a major slide on the downstream slope of the Upper San Fernando Dam, which was also damaged as a result of the earthquake. The Lower San Fernando Dam, which was being used only for flood control purposes, was damaged again during the 1994 Northridge Earthquake.

Several other dams have experienced damage during earthquakes. The Department of Water Resources (DWR) Division of Safety of Dams (DSOD) regulates approximately 1,250 dams and has been working with dam owners to periodically assess dam safety. Several dam owners have rehabilitated their dams.

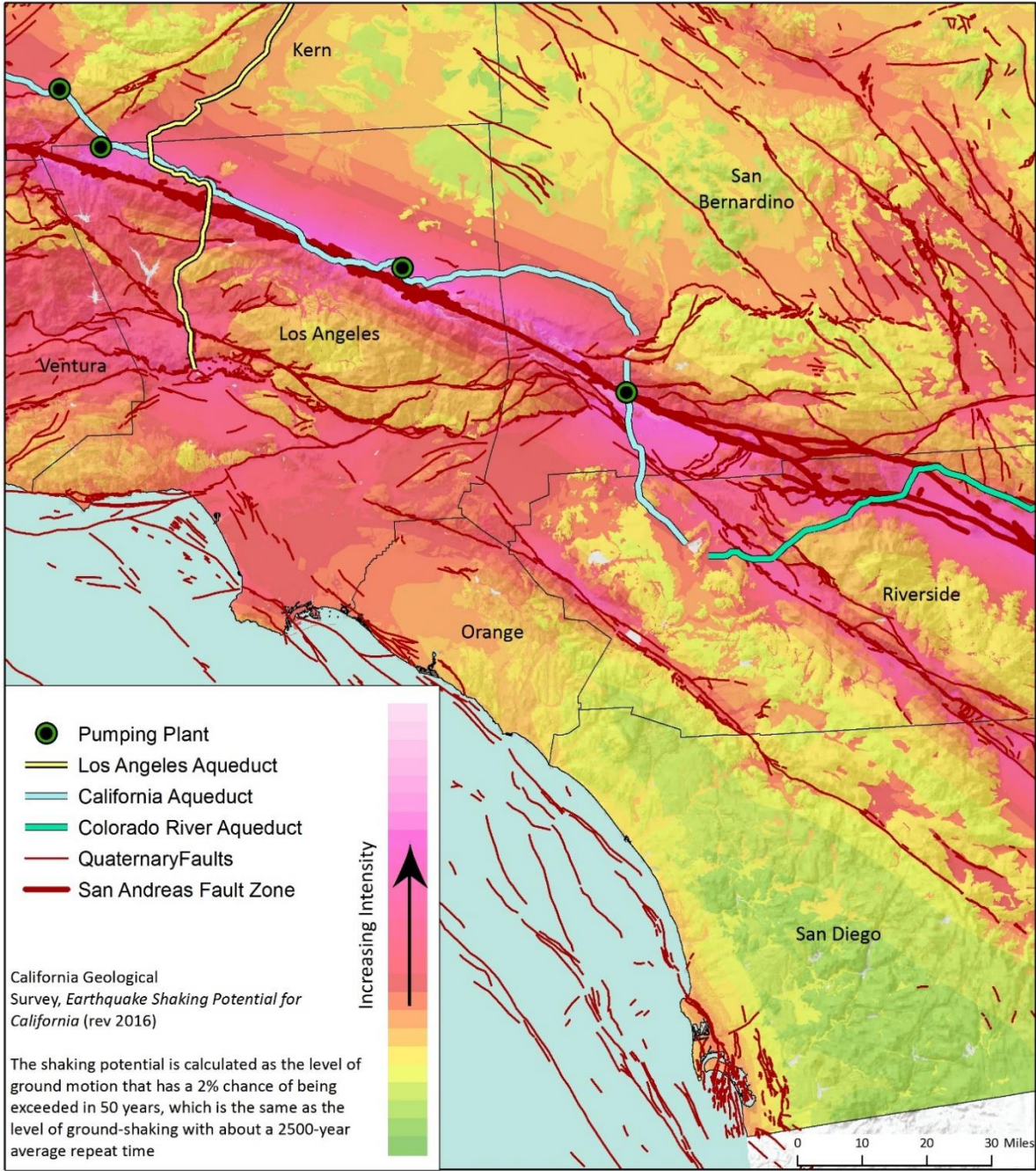
---

<sup>115</sup> California Seismic Safety Commission

<sup>116</sup> Torres, et al., 2000

Map 6.R: Southern California Water Resources Vulnerability to Earthquakes

# Southern California Water Resources Vulnerable to Earthquakes



Cal Poly, San Luis Obispo  
City and Regional Planning  
June 2018

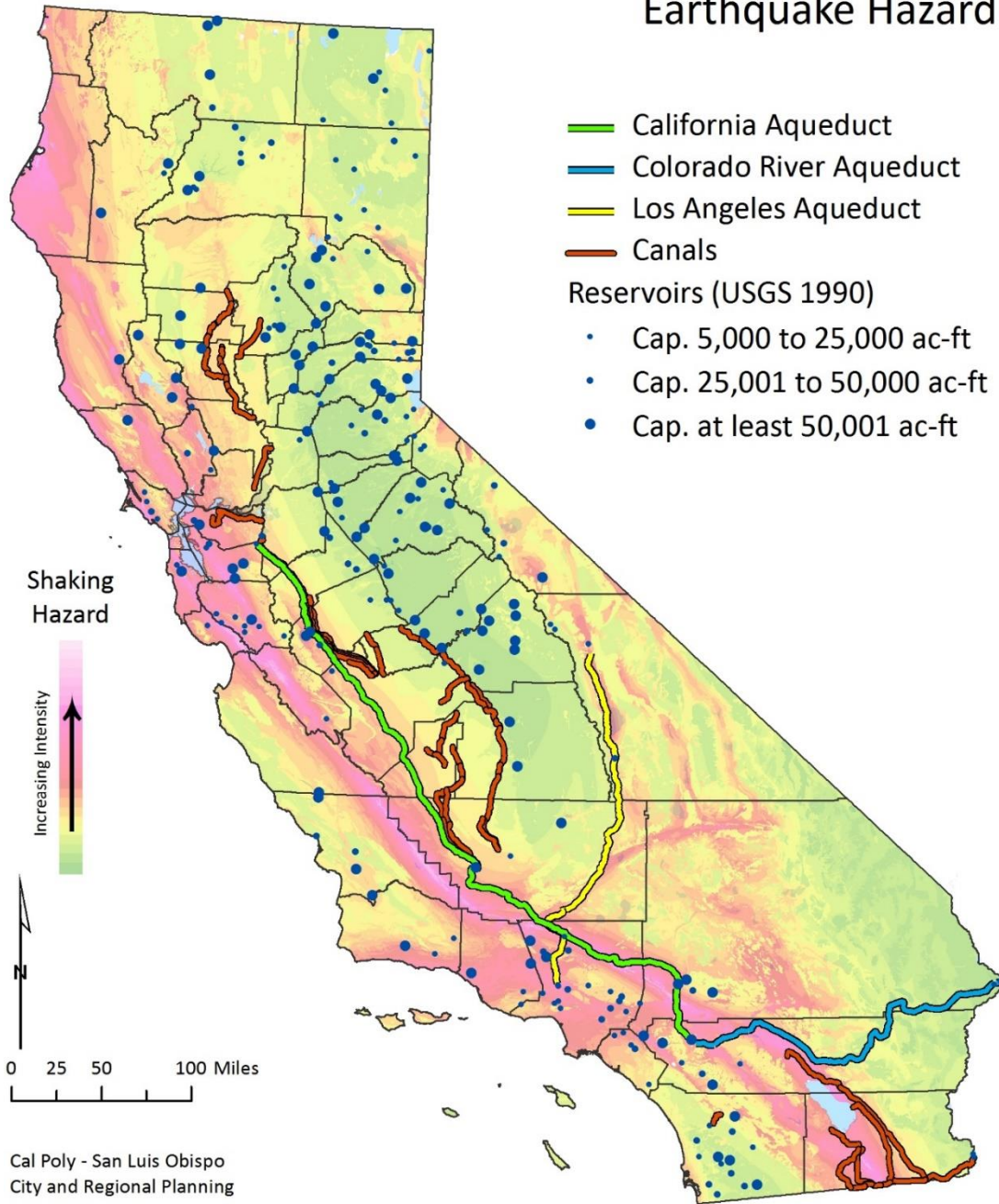
Sources: CGS, CA Natural Resources Agency, CA DWR

Created by: C. Schuldt (6.Q & Annex3.A--Southern Calif Water Resources Vulnerable to EQ.mxd)

Map 6.R shows an example of a location where the state’s water conveyance system is located in areas with high shaking intensity potential.

Map 6.S: California Aqueducts, Canals, Reservoirs, and Earthquake Hazard

## California Aqueducts, Canals, Reservoirs and Earthquake Hazard



Cal Poly - San Luis Obispo  
 City and Regional Planning  
 June 2018

Source: Earthquake Shaking Potential (rev. 9/30/16) is from Department of Conservation, California Geological Survey, and is protected by the United States Copyright Law. For more information, contact the California Department of Conservation, California Geological Survey.  
 U.S. National Atlas; USGS; ESRI Data & Maps

Created by: C. Schuldt (6.R-California Aqueducts, Canals and Earthquake Hazard.mxd)

Map 6.S shows the massive, complex system of state and federal aqueducts and canals by which water is transferred within the 10 hydrologic regions of California. The three major aqueducts transporting water to Southern California together traverse nearly 1,000 miles.

### 6. Solid Waste Disposal Systems (Municipal and Hazardous Waste Landfills)

There are more than 200 municipal and hazardous waste landfills in California. There is no inventory of municipal or hazardous waste landfill seismic hazard mitigation activities. During the siting, permitting, or closure process, a landfill owner may be required to submit a stability analysis for the liner and/or final cover systems. The purpose of the liners and the final cover is to prevent the uncontrolled release of leachate or landfill gas (a gas that is made up mainly of methane) from the landfill. This may vary from a simple analysis for flat slopes to a sophisticated seismic hazard assessment and slope stability analysis.

In general, the greatest vulnerability for landfills with respect to seismic hazards may be the damage to the final cover or the landfill gas collection and control system caused by ground deformation (in this case the deformation of the landfill). Another significant vulnerability of landfills is the loss of electrical power to run leachate collection and control systems and landfill gas collection and control systems.

### 7. Transportation Systems

Transportation systems are generally categorized as follows:

- Highways (including freeways)
- Bridges
- County or city roadways
- Railways

California has approximately 50,000 lane miles of highways. Since there is no single database including all roadways in the state, the total lane miles of county and city roadways are unknown. Bridge fragility and liquefaction represent hazards for these roadways. In addition, the seismic compression of embankment fills can cause minor damage at many locations affected by shaking resulting in an expensive overall fix. This was evidenced by the 2010 Chilean earthquake.<sup>117</sup>

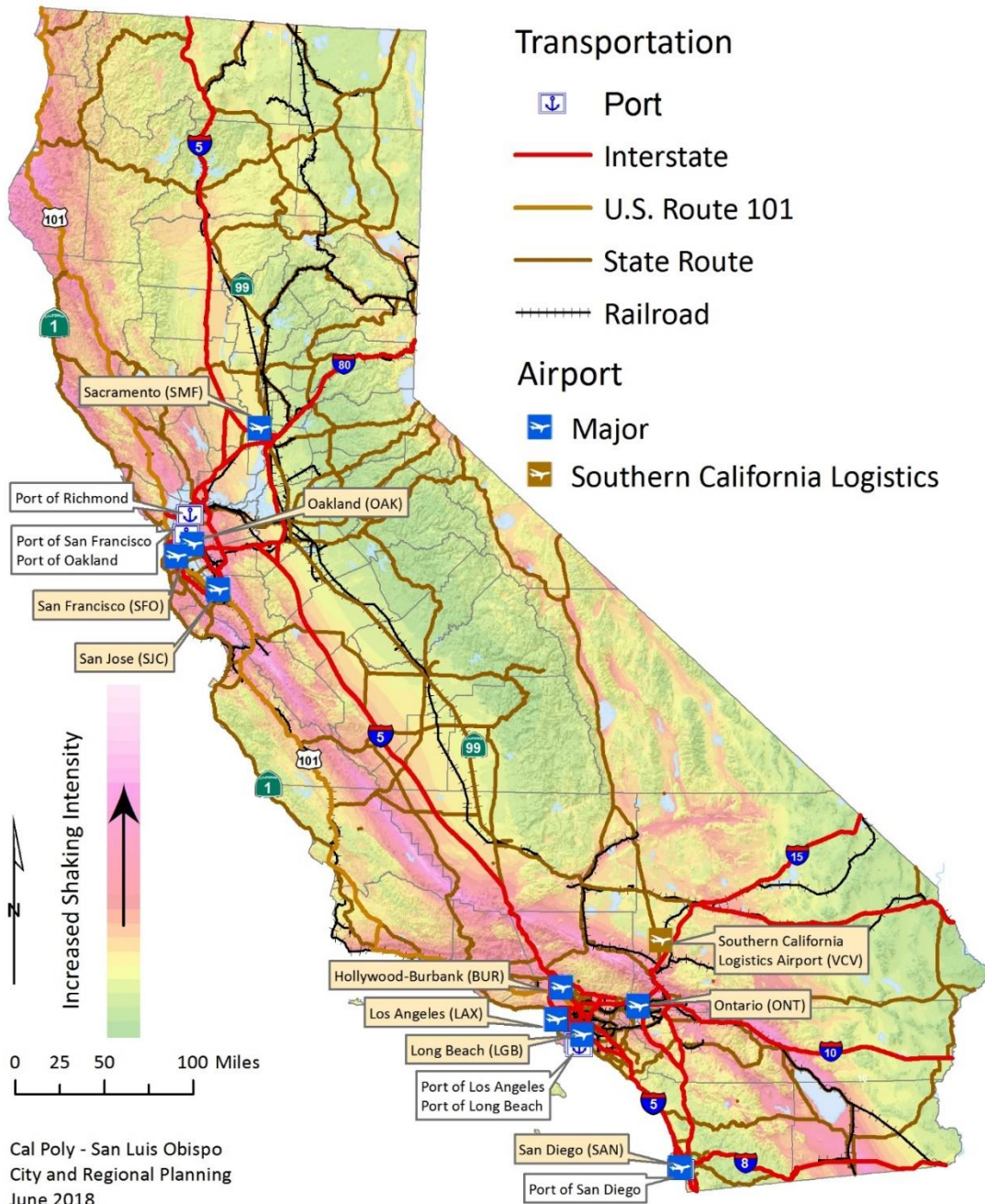
Map 6.T illustrates the locations of major transportation systems in the state in relation to potential shaking hazard.

---

<sup>117</sup> Arduino, P., Ashford, S., Assimaki, D., Bray, J., Eldridge, T., Frost, D., & Kayen, R. (2010). Geo-engineering reconnaissance of the 2010 Maule, Chile earthquake. GEER Association Report No. GEER-022, 1.

Map 6.T: Transportation Infrastructure and Shaking Intensity

# Transportation Infrastructure



Cal Poly - San Luis Obispo  
 City and Regional Planning  
 June 2018

1.0 second spectral acceleration with 2% probability of exceedance in 50 years

This information was produced by the Department of Conservation, California Geological Survey and is protected by the United States Copyright Law. For information, contact the California Department of Conservation, California Geological Survey.

Created by: C. Schuldt (6.S--Transportation Infrastructure and Shaking Intensity.mxd)

### 8. *Ports and Harbors*

There is no systematic integrated database or inventory on seismic hazard assessment or mitigation for ports and harbors in California. However, most of the large ports and harbors have initiated seismic hazard studies for various projects in recent years.

Ground deformation is a significant vulnerability in various ports and harbors since significant piers and quays are built out of dredge tailings or fill. Landfills do not typically perform well in large earthquakes, as evidenced by damage to human-made ground in the Marina District of San Francisco in the Loma Prieta Earthquake in 1989 and in 1995 in Kobe, Japan. Ground deformation on landfills at ports and harbors can affect harbors and ports by changing the alignments of tracks for large cranes used to load or off-load cargo ships. Such deformation may occur from lateral spreading, liquefaction, dynamic compaction, or secondary ground rupture. After the 1989 Loma Prieta Earthquake, some of the Oakland Airport's runways experienced severe ground deformation. This damage affected airport operations.

Ports, harbors, or other waterways containing a marine oil terminal pose a secondary hazard of potential oil spills or post-earthquake fire ignitions. Additionally, the spill clean-up efforts could result in port or harbor closures, affecting both response and recovery efforts.

Depending on the location, geometry, and depth of the port or harbor, it may be susceptible to a tsunami or seiche. Seismic waves traveling through shallow water and tsunamis in ports, harbors, and other waterways can significantly affect vessel operations and safety. For example, vessels in ports can bottom out in either event, or in a tsunami, vessels and other port and harbor systems (e.g., tanks, containers, etc.) can become moving hazards. Since 1946, when tsunami damage started to be more thoroughly documented, California has had at least eight tsunamis that have caused minor to major damage to ports and harbors. The most significant of these events was the March 11, 2011 tsunami from Japan, which caused over \$100 million in damage to 27 harbors statewide. For more information about tsunami and seiche hazards for harbors, and products that are being developed to respond to and mitigate these hazards, see [Section 7.3: Tsunami and Seiche Hazards](#).

Map 6.T shows major transportation infrastructure in California including freeways, other highways, railroads, international airports, and ports. Major north-south travel corridors include Interstates 5 and 99 and U.S. Highway 101. Major east-west travel corridors include Interstates 80, 15, 10, and 8. Major ports include San Francisco, Oakland, Richmond, Los Angeles-Long Beach, and San Diego. Much of this transportation infrastructure is in areas with potential for strong shaking intensity.

### 9. *Communication Systems*

California has no seismic hazard inventory for its communication systems. However, there is a guideline for the improvement of performance during earthquakes titled Methods of Achieving Improved Seismic Performance of Communications Systems (Tang and Schiff, 1996).

The vulnerability of communication systems depends the type of system under consideration. For example, switches and other aboveground components tend to be more affected by strong ground shaking than by liquefaction, while belowground conduits may be more affected by liquefaction than by shaking. In prior strong urban earthquakes, there has been little damage to cellular telephone or internet systems. However, their use has grown exponentially since the 1994 Northridge Earthquake. Their typical vulnerabilities stem from the loss of electrical power and from surges in customer use potentially swamping the capacity of the systems.

The seismic vulnerability of radio and television communication systems is typically from the loss of power and shaking damage to unsecured equipment.

The HayWired Scenario under development by the U.S. Geological Survey (USGS), the California Geological Survey (CGS) and other partners will provide new information regarding communications systems vulnerability. For more information about HayWired, see [Section 6.1.3.1](#).

### 6.1.4.3 AGRICULTURE VULNERABILITIES TO EARTHQUAKE

California agriculture is large, diverse, and complex. While farm and ranches are at the center of agriculture, the sector necessarily includes upstream farm supply industries and downstream processing, distribution and marketing. Earthquakes have the potential to cause damage and the loss of infrastructure that supports agricultural production, storage, and transport. Damage to lifelines including power, water, transportation, and communication are likely to be temporary and unlikely to cause long-term disruptions; however, damage to major hubs, including ports may have more substantial impacts.

In 2014, an academic research report was prepared for the California Seismic Safety Commission (CSSC) to assess the potential vulnerabilities of agriculture in the state based on several case studies, including the 2010 and 2012 earthquake affecting Imperial County, and an assessment of the Salinas Valley in Monterey County. The study documented that significant losses are a concern for primarily rural food and agricultural industries and concluded:

- Large areas of California agriculture, along the Mexican border, along the central and southern coast, and near the Sacramento-San Joaquin Delta are especially vulnerable to seismic activity
- The California produce industry is perhaps more vulnerable than any other to seismic disruptions because of both its location and the high levels of perishability. The Monterey County produce industry ships a high proportion of the nation’s vegetables and berries during its peak season, so disruptions would affect consumers as well as producers
- The most important dairy production and processing regions, in the Southern San Joaquin Valley, are less prone to seismic events than the coastal counties and Imperial County. Nonetheless, given extreme perishability and animal welfare concerns, dairies do need to have a high level of awareness of seismic risks

A full copy of the report (Earthquakes and California Agriculture: Where are the Vulnerabilities?) can be found at: [http://ssc.ca.gov/forms\\_pubs/earthquakes\\_and\\_california\\_agriculture\\_revised2.pdf](http://ssc.ca.gov/forms_pubs/earthquakes_and_california_agriculture_revised2.pdf).

### 6.1.4.4 LOCAL HAZARD MITIGATION PLAN HAZARD RANKINGS

An important source of local perceptions regarding vulnerability to earthquake threats is found in the collection of FEMA-approved and adopted Local Hazard Mitigation Plans (LHMPs) adopted by cities, counties, and special districts as of May 2017.

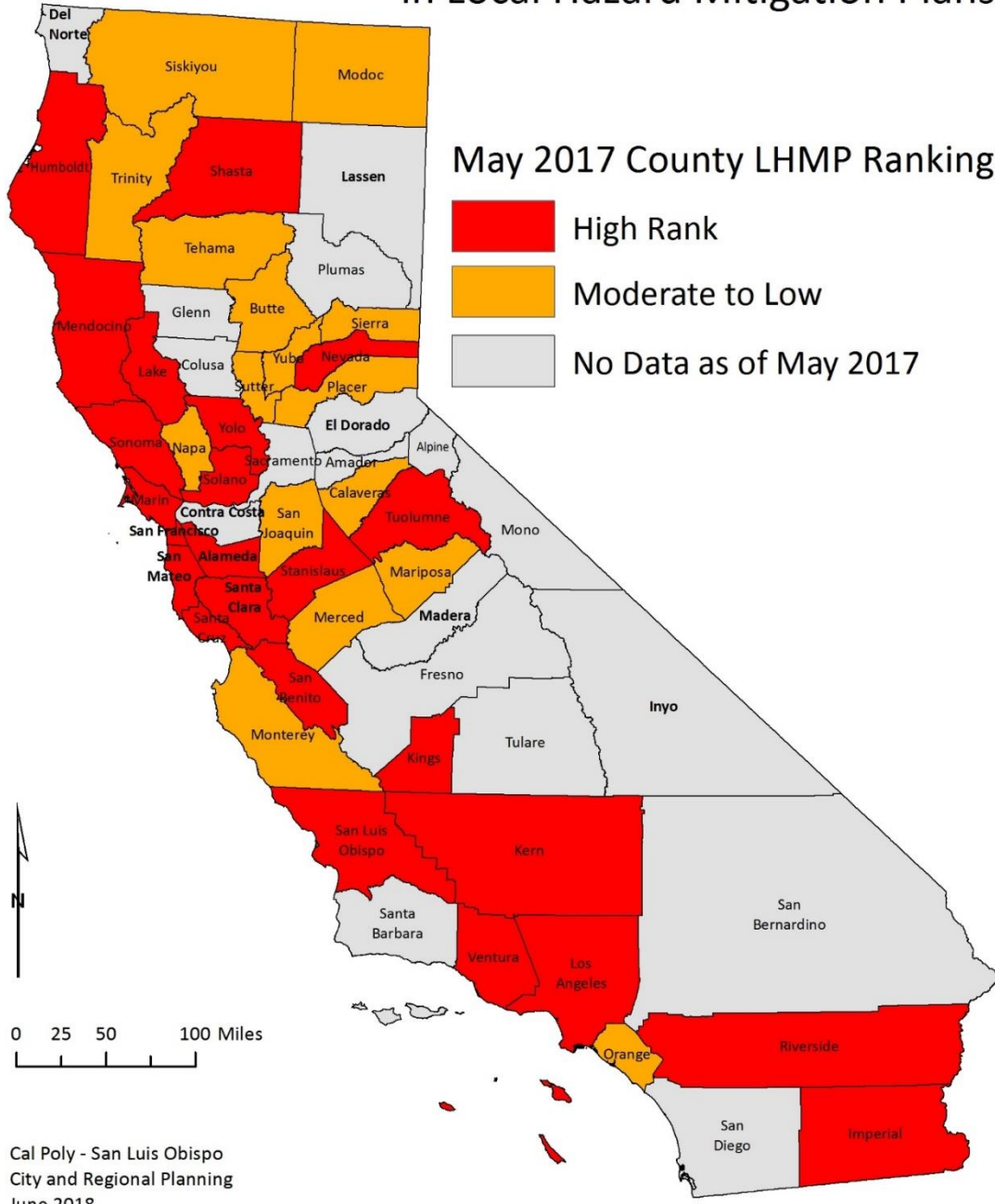
The most significant hazards reported in this review are earthquakes, floods, and wildfires—the three primary hazards also identified on a statewide basis by the 2010, 2013, and 2018 SHMPs. Including these three primary hazards, LHMPs identified a total of 58 distinct local hazards.

Map 6.U summarizes relative rankings of earthquake hazards in the 2017 review of LHMPs. Displayed are predominant earthquake hazard rankings shown as high (red) or moderate to low (orange) given by at least 51 percent of the jurisdictions with LHMPs within each county. Counties shown with gray color represent either jurisdictions not having a FEMA-approved and adopted LHMP or counties where data are missing or problematic.

For a detailed evaluation of LHMPs approved as of May 2017, see [Chapter 5: California Local Hazard Mitigation Planning](#).

Map 6.U: Earthquake Hazard Ranking in Local Hazard Mitigation Plans

## Earthquake Hazard Ranking in Local Hazard Mitigation Plans



Source: Inventory of approved and adopted California Local Hazard Mitigation Plans, Mike Boswell, Cal Poly-SLO, May 2017

Created by: C. Schuldt (5.B & 6.T--LHMP Earthquake Hazard Ranking.mxd)

Map 6.U identifies earthquake hazards as being a predominant concern in the 2017 LHMP review for all Southern California counties with approved LHMPs, as well as most San Francisco Bay Area counties. For those counties labeled as “no data,” either the approved LHMP did not include earthquake as a risk or there is no approved LHMP for that county.

## Implications for Local Loss Potential

Local hazard rankings are highly variable, responding to a wide variety of very specific local conditions. Each county and city has its own set of variables conditioning earthquake loss potential within its jurisdictions. Descriptions of loss potential are very specific within individual LHMPs and are not consistently drawn up between plans, nor is there even coverage of all cities and unincorporated areas. Such variability will diminish as more cities and counties prepare LHMPs and greater standardization enables comparability of local data with statewide data.

## Comparisons with Statewide Vulnerability

The majority of LHMPs reviewed in 2017 in all Southern California and nearly all San Francisco Bay Area counties rated earthquakes high in their hazard rankings, as shown in Map 6.U. Additionally, most Central Coast and North Coast counties and two eastern Sierra counties also rated earthquakes high. This is consistent overall with the patterns of earthquake hazards and population/social vulnerability patterns identified and discussed in [Section 4.4](#) of [Chapter 4: Profiling California's Setting](#).

### 6.1.5 CURRENT EARTHQUAKE HAZARD MITIGATION EFFORTS

The preceding discussion included a description of most recent earthquake events and earthquake hazard vulnerabilities by type of buildings, infrastructure, and transportation. In recent decades California has invested significant funds in seismic mitigation efforts. This is an indicator of the level of effort to mitigate seismic hazards and reduce life and property loss after earthquakes.

#### 6.1.5.1 EARTHQUAKE GROUND FAILURE MITIGATION

##### Earthquake Zones of Required Investigation

The State of California has developed a unique method to mitigate hazards related to ground failures caused by earthquakes. Through the Alquist-Priolo Earthquake Fault Zoning Act of 1972, which addresses hazards associated with surface fault rupture, and the Seismic Hazards Mapping Act of 1990, addressing hazards from soil liquefaction, landslides, amplified shaking, and tsunamis, the California Geological Survey (CGS) delineates regulatory earthquake zones of required investigation over the state's most populated areas and most hazardous faults. Other than strong ground shaking, earthquake hazards are not generally addressed in building codes and therefore have not always been treated consistently throughout the state.

The zones delineated by the CGS are regulatory in that local lead agencies are required by statute to incorporate them into their local ordinances, safety elements of general plans, and other planning documents, and are required to use them in the course of approving development plans for structures for human occupancy. Specifically, local governments must require site-specific investigations for hazards identified by the zones and cannot approve projects, that is, issue permits, unless the investigations either show the hazard does not exist or incorporate mitigation measures into the development plans. Another important aspect of the regulatory zones is that California disclosure laws require real estate sellers to inform buyers if a property for sale is located within these hazard zones.

Three basic premises are involved in this mitigation approach. First, earthquake hazards are best identified and mitigated at the site-specific level. Regional hazard identification maps—such as landslide or liquefaction inventories—do not provide enough information on potential future occurrences of these hazards, and susceptibility maps typically identify multiple levels of hazard that are not easily or uniformly implemented, if implemented at all. CGS hazard zones are developed with the best available geologic, geotechnical, terrain, and hydrogeologic data and evaluated with the best available analysis techniques so that they can be relied upon as a screening tool for requiring site-specific investigations. The second premise is that oversight and implementation of hazard mitigation measures are best applied by local lead agencies who have the authority to approve projects and the responsibility to protect their citizens from earthquake hazards. While lead agencies have some leeway in the implementation of hazard mitigation, with detailed guidance documents and outreach from the CGS, lead agencies throughout the state are addressing hazards to a consistent standard-of-practice where hazard zones exist. Finally, mitigation activities are

best applied prior to or during development construction – it is far more expensive to investigate and mitigate ground failure hazards after structures have been built. Building mitigation measures into new developments makes them resilient to future earthquakes, saving lives and reducing earthquake recovery costs.

### **Progress Summary 6.C: Earthquake Zones of Required Investigation (formerly called Seismic Hazards Mapping Projects) and Other Earthquake Data**

**Progress as of 2018:** Progress as of 2018: Since 2013, 10 Official Seismic Hazard Zone Maps have been issued by the California Geological Survey (CGS): four in Contra Costa County, four in Riverside County, and two in San Mateo County. This brings the total number of Official Seismic Hazard Zone Maps issued since the program’s inception to 124, affecting 170 cities and 10 counties. This total represents roughly one third of the identified high risk areas in the state where these zones are needed to increase mitigation efforts for liquefaction and landslide hazards. It is anticipated that funding from the Federal Emergency Management Agency (FEMA)/California Governor’s Office of Emergency Services (Cal OES) Hazard Mitigation Grant Program will increase the rate at which these important zones are delineated.

Also since 2013, 21 new and revised Alquist-Priolo Earthquake Fault Zone Maps have been issued, affecting the following counties: El Dorado, Orange, Los Angeles, Napa, Riverside, San Bernardino, and Solano. This brings the total number of maps issued since the program’s inception in 1972 to 560, affecting 119 cities and 37 counties. Progress in fault zoning is continuing in Southern California along the Rose Canyon and Elsinore Faults, and along the West Napa, Rodgers Creek, and Healdsburg Faults in Northern California.

Special Publication 42, which provides guidance on identifying and mitigating hazards from surface fault rupture, was significantly revised in 2017.

In 2017, all regulatory zone data were re-processed and modernized, and are now available multiple formats. Portable document file (PDF) maps and reports, as well as tiled Geographic Information Systems (GIS) data, are available through the CGS Information Warehouse:

<http://maps.conservation.ca.gov/cgs/informationwarehouse/index.html>.

GIS data are also available as web and feature services:

[https://spatialservices.conservation.ca.gov/arcgis/rest/services/CGS\\_Earthquake\\_Hazard\\_Zones](https://spatialservices.conservation.ca.gov/arcgis/rest/services/CGS_Earthquake_Hazard_Zones).

To assist property owners, real estate professionals, and prospective property buyers, the CGS has created a Regulatory Zone GeoApplication that includes Earthquake Fault Zones, Landslide Zones, and Liquefaction Zones, based on a pre-processed California State parcel dataset: <https://maps.conservation.ca.gov/cgs/EQZApp/>.

### **Progress Summary 6.D: EQ Zapp: California Earthquake Hazards Zone Application**

**Progress as of 2018:** The California Geological Survey (CGS) has launched the California Earthquake Hazards Zone Application (EQ Zapp), an online mapping tool that allows anyone with a computer, tablet, or smartphone to conveniently check whether a property is in an earthquake hazard zone.

With EQ Zapp, the user can type in an address or use the location capability in the computer or device to determine whether a property lies within any of the CGS’s mapped earthquake hazard zones. It will also indicate if the CGS has not yet evaluated the hazards in that area. Earthquake hazard zones define areas subject to three distinct types of geologic ground failures:

- Fault rupture, in which the surface of the earth breaks along a fault
- Liquefaction, in which the soil temporarily turns to quicksand and cannot support structures
- Earthquake-induced landslides

Although strong ground shaking is responsible for most earthquake-related damage, these zones identify areas where earthquake hazards other than structural shaking—specifically ground failures during an earthquake—are more likely. The zones trigger geologic and engineering investigations that can identify and mitigate the ground failure hazard before construction begins, thereby making the structure itself more resilient to potential shaking.

The CGS also provides the earthquake hazard zone data as portable data file (PDF) maps and reports, or as Geographic Information Systems (GIS) shapefiles through the CGS Information Warehouse. GIS data available from the CGS can be reviewed through the Geologic Hazards Data Viewer and Data List, at the following links:

<http://maps.conservation.ca.gov/cgs/informationwarehouse/index.html?map=regulatorymaps>

<https://maps.conservation.ca.gov/geologichazards/#dataviewer>

<https://maps.conservation.ca.gov/geologichazards/#datalist>

Prior to launching EQ Zapp, the CGS completely updated all of the regulatory hazard zones, including Alquist-Priolo fault zones and Seismic Hazard Zones. This included updating PDF, GIS, and report data, and relocating them from multiple servers to a single, more logical and comprehensive location. That project was completed in the spring of 2017 with a release of statewide web services/interactive maps and updates to the CGS Information Warehouse where project information can be obtained as tiled data.

For more information, visit: [http://www.conservation.ca.gov/cgs/Pages/SH\\_EQZ\\_App.aspx](http://www.conservation.ca.gov/cgs/Pages/SH_EQZ_App.aspx).

Maps 6.V and 6.W show progress in meeting long-term program goals for seismic hazard mapping.

#### **Best Practices Highlight 6.A: Successful Update of Alquist-Priolo Map for Lake Tahoe Area Clarifies Fault Location**

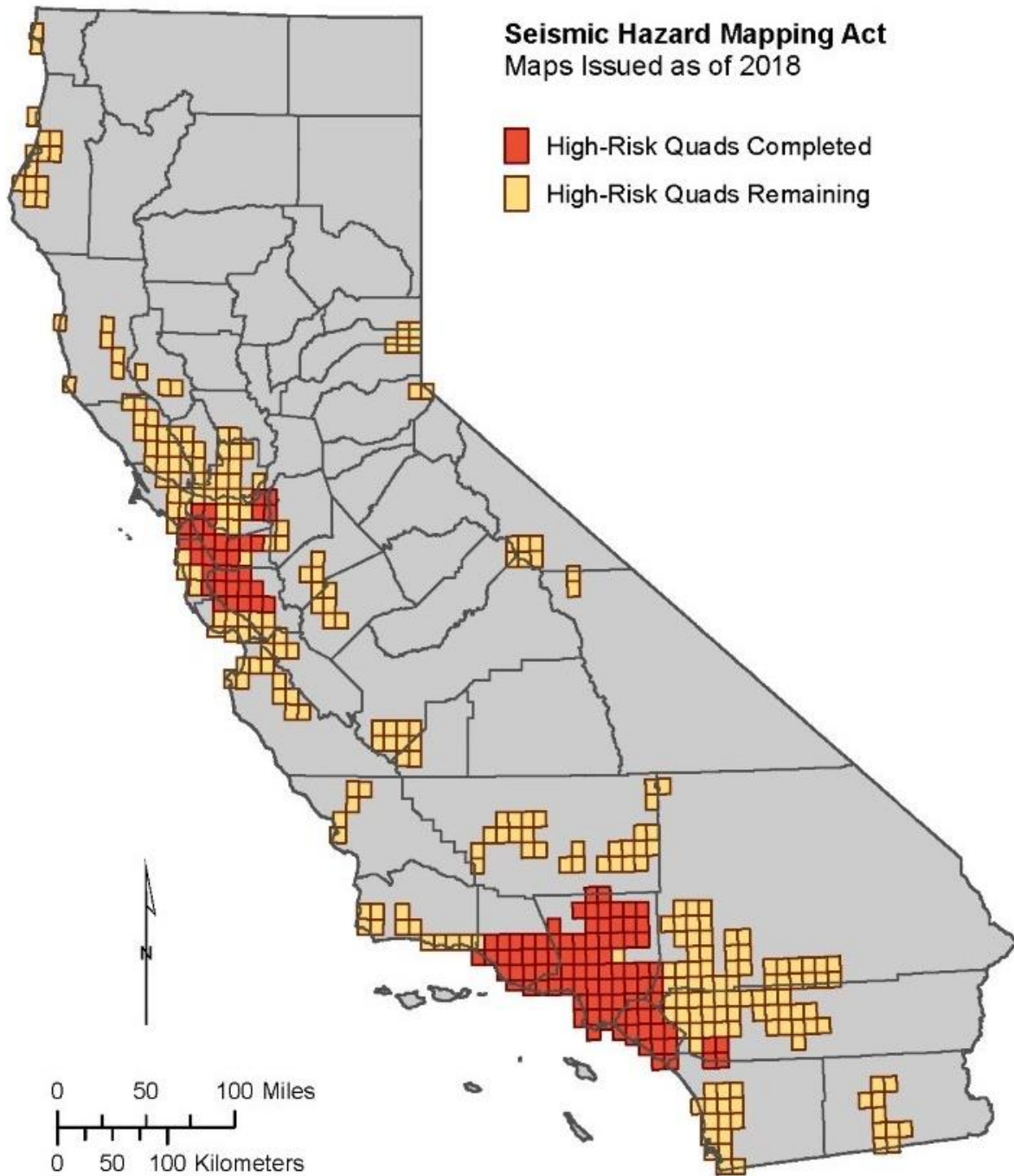
##### **Mitigating Surface Faulting Hazards in the Lake Tahoe Basin**

The Alquist-Priolo Earthquake Fault Zoning Act provides a mechanism for reducing losses from surface fault rupture on a statewide basis by having the California Geological Survey (CGS) identify earthquake zones of required investigation around active faults. Public safety is enhanced by lead agencies in requiring site-specific fault investigations for developments within these zones and mitigating fault rupture hazards by avoidance.

For many years, geologists suspected that several faults in the Lake Tahoe Basin were active but were unsure of their exact locations onshore. In addition, the great depth of Lake Tahoe prevented careful study of these faults on the lake bottom. Several state and federally funded research efforts over the past decade were used to identify and characterize active faulting in the Lake Tahoe Basin. The research efforts resulted in high-resolution bathymetric and topographic images of the Tahoe Basin area that could be used to accurately locate the faults and measure the timing and amount of past earthquake fault ruptures. Three active fault traces are now known to cross the onshore portions of the basin and the lake floor. These faults are among the most significant seismic sources in the region and, where these faults exist onshore, present a significant surface rupture hazard to buildings.

A CGS fault-trenching research study of the West Tahoe Fault (funded by the U.S. Geological Survey [USGS] External Grants Program) at the south end of the lake provided direct evidence of three large-magnitude earthquakes in the past 10,000 years that had significant surface ruptures. Based on all the recent studies, the CGS delineated earthquake fault zones in the southern onshore portion of the West Tahoe Fault. The earthquake fault zones cover portions of two 7.5-minute topographic quadrangle maps in El Dorado County that are now the basis for mitigating the hazard from surface faulting. Future plans consist of preparing a series of fault zone maps for the active faults that are located on the north side of Lake Tahoe and continue through the city of Truckee. Additionally, other earthquake hazard zone mapping is planned to include liquefaction, earthquake-triggered landslides, and tsunami wave inundation.

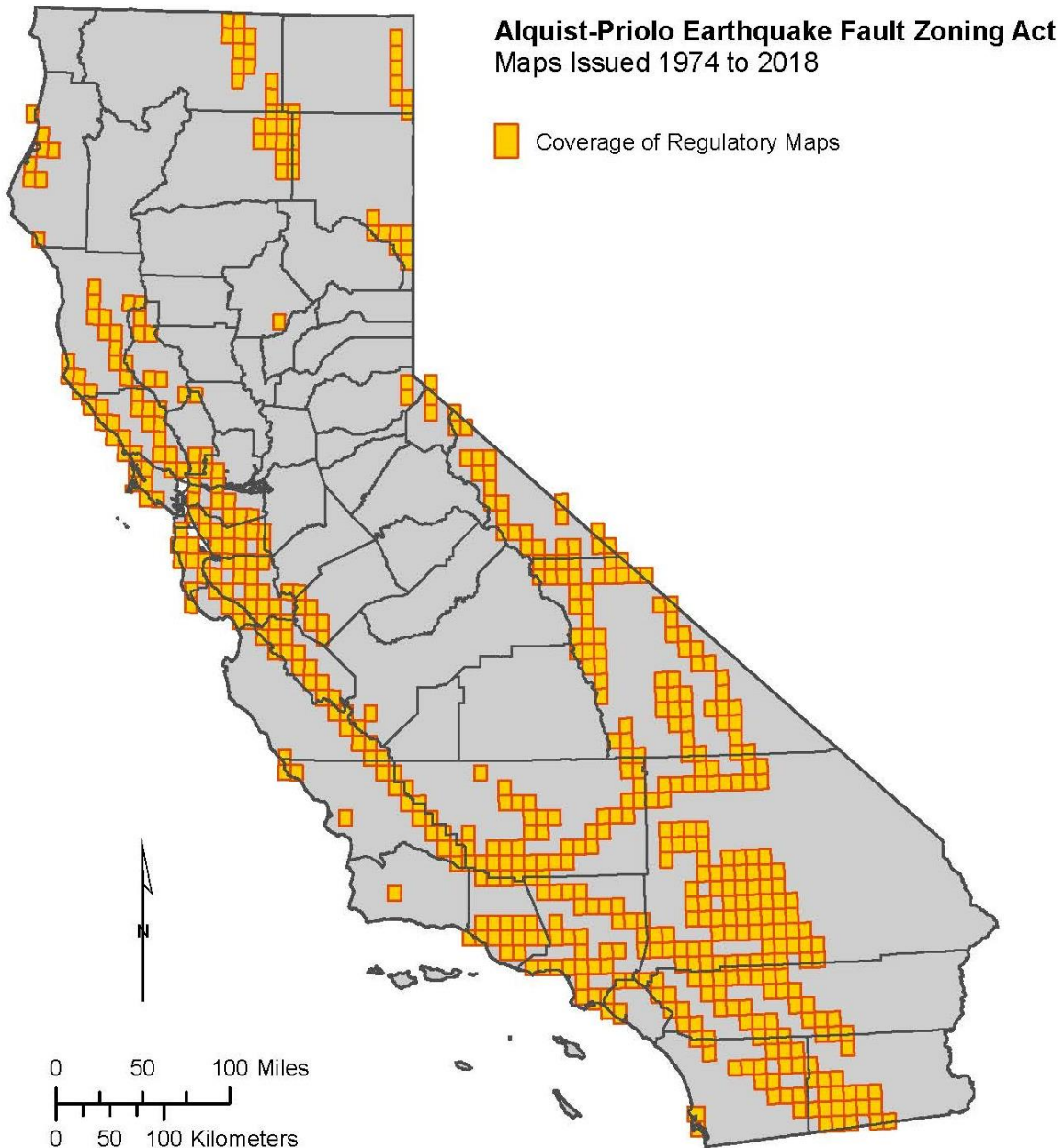
Map 6.V: Seismic Hazards Mapping Act Progress as of 2018



Source: California Geological Survey

Map 6.V shows completion of Seismic Hazards Mapping Act mapping in areas of high seismic risk, primarily in Southern California and the San Francisco Bay Area.

**Map 6.W: Alquist-Priolo Earthquake Fault Zoning Map as of 2018**



*Source: California Geological Survey*

Map 6.W shows the areas of the state covered by Alquist-Priolo Earthquake Fault Zoning Act maps issued as of early 2018. Most recent maps completed have been in El Dorado, Los Angeles, Napa, Orange, Riverside, and San Bernardino Counties.

## Post-Earthquake Damage Assessment - California Earthquake Clearinghouse

California Public Resources Code requires the California Geological Survey (CGS) to operate a clearinghouse for post-event earth science investigations. In addition, the National Earthquake Hazards Reduction Program (NEHRP) directs state and federal agencies to coordinate on the collection of post-earthquake information through a clearinghouse. Over the years, this function has evolved into what is known as the California Earthquake Clearinghouse, which is run jointly by the CGS, Earthquake Engineering Research Institute, Cal OES, USGS, and California Seismic Safety Commission (CSSC). Following large and damaging earthquakes, the Clearinghouse activates and establishes a physical location and a virtual/online presence provided by the Clearinghouse website. A federal disaster declaration is not required for Clearinghouse activation. The principal function of the Clearinghouse is to promptly gather information on ground failure, structural damage, and other consequences from significant seismic events and share it with state and federal disaster response managers and the scientific and engineering communities.

In order to accomplish information sharing objectives, the Clearinghouse leverages XchangeCore (formerly known as Unified Incident Command and Decision Support [UICDS]) technology, which was developed by the U. S. Department of Homeland Security (DHS) and Department of Defense (DOD) for information exchange via web services. The Clearinghouse information-sharing capabilities can simultaneously serve and receive geospatial and non-geospatial information from scientists and engineers in the field, operational area Emergency Operation Centers, and multiple organizations, all using many different XchangeCore-connected applications. The Clearinghouse provides all users with free access to the SpotOnResponse application, a crowd-sourcing and location-based situational awareness mobile and web application. In addition to emergency response, Clearinghouse information-sharing capabilities also support pre-event preparedness planning, risk assessment/mitigation decision-making, understanding interdependencies of critical infrastructure, and developing regional earthquake resilience to promote more rapid recovery. For more information on the California Earthquake Clearinghouse, activations, exercises, and information-sharing tools and capabilities, please visit:

<http://californiaeqclearinghouse.org/>.

### Best Practices Highlight 6.B: California Earthquake Clearinghouse Achievements 2010-2017

*National Recognition:* Clearinghouse-information sharing and technology interoperability efforts received the following recognition at the national level:

- 2014 recommendation from the U.S. Geological Survey (USGS) - Open Geospatial Consortium Interoperability Assessment to use XchangeCore as exemplified by the California Earthquake Clearinghouse
- 2015 recognition of Clearinghouse information sharing achievements as “Geospatial Concept of Operations Best Practice” by the U.S. Department of Homeland Security (DHS)

*Earthquake Response:* The Clearinghouse has supported state response to two earthquakes, including a federally declared disaster:

- 2014 Magnitude 5.0 La Habra Earthquake.
- 2014 Magnitude 6.0 South Napa Earthquake (DR-4193\*)

*Earthquake Exercises:* The clearinghouse participated in nine federal, state, and military earthquake-themed exercises between 2011 and 2016, partnering with:

- 10 federal agencies
- 22 state and local governmental agencies
- 7 academic and research organizations
- 12 non-governmental organizations
- 12 neighboring states and international jurisdictions (for Cascadia and other tsunami exercises)
- 16 private sector organizations

*Funding:* The Clearinghouse has no sustained funding, but accomplishes goals through the following competitive grants:

- 2013 National Earthquake Hazards Reduction Program (NEHRP) grant: \$85,000

- 2014 NEHRP grant: \$70,000
- 2015 Federal Emergency Management Agency (FEMA) grant: \$50,000
- 2016 FEMA grant: \$50,000
- 2017 FEMA grant: \$30,000

*Operational Improvements:* The Clearinghouse has been advancing the use of digital field data collection by providing improved cross-platform, real-time data sharing through the

- SpotOnResponse mobile field data collection and situational awareness application. Available in a web browser or on smart phones or tablets

*Outreach:* The Clearinghouse depends on the collaboration of partner organizations and has conducted a wide range of outreach activities, including:

- Nine statewide outreach events. The Clearinghouse conducts outreach events to inform partners of important activities, and to allow partners to provide feedback to define Clearinghouse priorities.
- Twelve one-hour training sessions conducted with partners on Clearinghouse information-sharing capabilities, recorded and available on YouTube
- Weekly coordination calls (for the last 6+ years)
- Information sharing training guides for XchangeCore connected applications

\* Federal Disaster Designation Number

## 6.1.5.2 MITIGATION OF POTENTIAL BUILDING LOSSES

### Overview

Seismic shaking, which caused over 98 percent of the losses in the Loma Prieta Earthquake, has long been recognized as the main threat to structures during earthquakes. To mitigate this hazard, building codes have been steadily improved over the past 80 years as the understanding of seismic shaking has improved based on strong motion data gathered by the CGS and USGS. Current California building codes include provisions for considering the potential shaking from earthquakes, including stronger shaking near faults and amplification by soft soils.

The most effective single element in mitigating earthquake losses to buildings is the consistent application of a modern set of design and construction standards, such as those incorporated in modern building codes. The codes are updated regularly to include the most effective design and construction measures that have been found by testing and research or observed in recent earthquakes to reduce building damage and losses.

The building code has been the main mitigation tool for seismic shaking in most buildings, although hospitals, schools, and other critical facilities are subject to additional mitigation measures, as discussed below. The following are the current building codes and standards upon which state and local codes are based.

- The 2018 International Building Code, which offers the most current and innovative set of regulations for new commercial construction
- The 2018 International Residential Building Code, which covers requirements for new residential construction
- The 2018 International Existing Building Code, which contains requirements intended to encourage the use and reuse of existing buildings including provisions for seismic retrofit

(The above are being considered for adoption as part of the 2019 California Building Standards Code.)

The 2016 California Building Codes are based on the 2015 edition of the International Building Code. Design standards for existing and new construction that are incorporated into the International Building Code and the California Building Codes are based on state-of-the-art knowledge, developed through a peer review process by the American Society of Civil Engineers (ASCE) and the Structural Engineering Institute (SEI). Their most recent publications governing seismic design and retrofit include:

- ASCE/SEI 41-13: Seismic Evaluation and Retrofit of Existing Buildings

- ASCE/SEI 7; Minimum Design Loads and Associated Criteria For Buildings and Other Structures (New Construction)

The 2016 California Building Standards Code, also referred to as Title 24 (effective January 1, 2017) provides design standards for existing and new construction, and includes the following parts:

- The California Building Code
- The California Residential Code (for new construction)
- The California Existing Building Code (for existing structures)
- The California Electrical, Mechanical, Plumbing, Energy, and Green Building Standards (CALGreen) Codes
- The California Historic Building Code
- The California Fire Code

As of early 2018, local government building departments use the 2016 California Building Code, and the 2016 California Existing California Building Code, adopted from the 2015 International Building Code and the International Existing Building Code with local amendments to regulate the vast majority of buildings. Acute care hospitals, public K-12 schools, and state-owned buildings, are regulated by the 2016 California Building Code and more stringent amendments prepared by applicable state agencies, as noted in the following discussion.

For new buildings, state and local governments will enforce the 2016 California Building Standards Code which includes earthquake safety provisions from the 2015 International Building Code with enhancements for hospitals, public schools, and essential services buildings. The adoption date of the 2018 International Building Code is January 2019 with an effective date of January 1, 2020.

A small percentage of older buildings have been strengthened or “retrofitted” to improve their resistance to earthquake shaking. Observations after recent earthquakes suggest that retrofitted buildings on the whole perform noticeably better than similar buildings that have not been retrofitted (ATC 31, 1992, CSSC 94-06, WJE 1994).

Fewer than five percent of California’s existing buildings have been structurally retrofitted; the actual number has not been determined. However, the California Earthquake Authority’s Earthquake Brace+Bolt program (EBB) has provided grants for more than 5,000 code-compliant retrofits for single-family wood-frame dwellings between 2013 and mid-2018. The EBB program expects to fund a minimum of another 6,000 retrofits between 2018 and 2021. The California Building Code generally allows retrofits of any nature provided that they make existing buildings no less safe. These regulations and the 2015 and 2018 International Existing Building Codes are available for use at the discretion of all state and local regulatory agencies. They include a compilation of seismic evaluation and retrofit provisions for unreinforced masonry, tilt-up, wood-frame dwellings, and older concrete buildings. A separate California Historical Building Code (California Building Standards Code 2016b) contains provisions for evaluating, rehabilitating, and altering historical buildings. The California Seismic Safety Commission published a Guide to Identify and Manage Seismic Risks of Buildings for Local Governments to assist local government agencies in assessing the vulnerability of their building stock.

Mitigation measures for ground failure hazards include avoiding the hazard, strengthening foundations, and modifying soils below foundations. Refer to CGS Special Publication 117, “Guidelines for Evaluating and Mitigating Seismic Hazards in California” (<http://www.conservation.ca.gov/cgs/shzp/webdocs/Documents/sp117.pdf>) and CGS Special Publication 42, “Earthquake Fault Zones in California, A Guide for Government Agencies, Geoscience Practitioners, and Property Owners/Developers” (<ftp://ftp.consrv.ca.gov/pub/dmg/pubs/sp/Sp42.pdf>).

## Mitigation of Buildings by Type or Sub-Inventory

### *1. Mitigation for State-Owned and-Leased Structures*

The California Vital Infrastructure Vulnerability Assessment (Cal VIVA) was begun during preparation of the 2010 SHMP. Its purpose was to develop and test a methodology for assessing the vulnerability of state-owned building stock and critical infrastructure to seismic and other hazards and determine minimum retrofit measures to protect

its occupants from harm during a disaster and facilitate recovery by making facilities quickly operable after a disaster. Cal VIVA III, prepared in association with EERI, tested and refined the Cal VIVA II prototypical department plan with an individual user department and produced a template that can be used by departments and agencies within state government to systematically address critical building vulnerability and support planning for potential retrofits on a long-term basis.

### *2. Mitigation for State-Regulated Essential Services Buildings*

California enacted the Essential Services Buildings Seismic Safety Act of 1986 and DSA adopted regulations that apply to all new construction (Title 24, Part 1). For existing essential services buildings owned by the state, the California Building Standards Commission adopted regulations in Part 10 of the 2016 California Building Code that apply to building seismic evaluations and retrofits. California has also adopted a national standard, ASCE/SEI 7-16, Minimum Design Loads and Associated Criteria for Buildings and Other Structures, and ASCE/SEI 41-13, Seismic Evaluation and Retrofit of Existing Buildings, as a retrofit standard for state-owned essential services buildings.

### *3. Mitigation for Other State-Owned Normal Occupancy Facilities*

In 1990, the state passed the Earthquake Safety and Public Buildings Rehabilitation Bond Act (Proposition 122), which authorized \$250 million for the identification and seismic retrofit of deficient state-owned buildings and \$50 million for seismic retrofit of local government essential services facilities. According to a Proposition 122 progress report issued in December 2008 by the Department of General Services (DGS), program funds had benefited 85 projects, with 55 completed, 1 under construction, 26 in various preparatory stages of design, and only 3 cancelled. According to DGS, the Proposition 122 program will ultimately result in the retrofit of over 145 buildings, totaling over 5 million square feet. Most importantly, the retrofits will protect a population of more than 70,000 employees and individuals in institutions.<sup>118</sup> According to a 2002 assessment by the California Seismic Safety Commission, 61 state buildings were retrofitted, and 132 local government buildings were retrofitted with matching funds. A 2002 report by the DGS noted that nearly all Proposition 122 funds have been expended or are earmarked for projects.

In 1999, the DGS Real Estate Services Division estimated the cost for retrofitting all state buildings as \$0.84 to \$1.7 billion. In 2002, the state began a program to transfer facility funding and operations for county courthouses to the Judicial Council. Seismic evaluations are required as part of the negotiation between the counties and the state.

For existing buildings owned by the state, the California Building Standards Commission adopted regulations now in Part 10 of the 2016 California Building Code that apply to seismic evaluations and retrofits.

### *4. Mitigation for State Criminal Justice and Judicial Court Buildings*

Since the Department of Corrections 1979-1980 renovation and planning study identified required seismic remediations, some prisons have been retrofitted in conjunction with other planned modernization projects. Together the Department of Corrections, Department of Justice, and California Youth Authority own:

- 33 prisons
- 38 correctional conservation camps
- 11 youthful offender institutions
- 12 crime laboratories

The California Building Standards Commission has adopted regulations now in Part 10 of the 2016 California Building Code for the seismic evaluation and retrofit of state criminal justice buildings, as well as ASCE 41-13 and ASCE/SEI 7-16.

The Judicial Council Program published the Seismic Risk Rating Study of California Superior Court Buildings report in March 2017. Action plans are provided in the Recommended Action Plans and Follow-up Activities section of the report to address selected judicial structures identified as Risk Level V (risk of collapse or major risk to life).

<sup>118</sup>California Department of General Services. "State-Owned Buildings Bond Act Expenditures Status Report." December 2008.

### 5. *Mitigation for State-Owned Health Services*

The state's acute care hospitals are exempt from the Alquist Hospital Seismic Safety Act. However, the state remains responsible for the public's seismic safety in these facilities. For state-owned buildings, the California Building Standards Commission has adopted regulations (see Chapter 34 of the 2013 California Building Code) that are applicable to seismic evaluations and retrofits. California has also adopted a national standard, ASCE/SEI 41-13, Seismic Evaluation and Retrofit of Existing Buildings, as a retrofit standard for state-owned buildings.

### 6. *Mitigation for Public Universities*

As of early 2018, the University of California (UC) system includes approximately 133 million gross square feet of space in over 5,970 buildings. These buildings include classrooms, offices, laboratories, specialized research facilities, libraries, and residential space to house students. Since the early 1970s, UC has been evaluating and retrofitting buildings on its campuses. The system has ranked the seismic safety of its major buildings from "good" to "very poor" (known as III to VI in the 2017 updated version of UC's seismic safety policy) and has embarked on capital outlay programs to retrofit those that are ranked "poor" (or V) in accordance with the updated policy or "very poor" (or VI in accordance with the updated policy). In the early 1990s, the California State University (CSU) system initiated a similar program. As of 2003, CSU had evaluated 1,364 major facilities, identified 145 as potentially hazardous and required further evaluation and retrofits in many cases.

As discussed further below, most facilities identified as hazardous now have retrofit projects undergoing design or construction or completed. The greatest vulnerability aspects of public universities are the potential for loss of life, research, and educational functions and damage to state property.

For existing public university buildings owned by the CSU and UC systems, the California Building Standards Commission has adopted regulations (see Part 10 of the 2016 California Building Code) that are applicable to seismic evaluations and retrofits. Both university systems have active seismic safety programs with major long-term capital programs including billions of dollars in mitigation investments.

#### **CSU Seismic Peer Review Board.**

Since 1993, CSU has had a vigorous program of reducing the unacceptable seismic risk of existing buildings and managing current construction programs to limit future seismic risk to acceptable levels. Seismic peer review is a mandatory part of the CSU construction process. Consistent with Title 24, CSU has adopted minimum seismic parameters. These campus-specific coefficients seek to provide more accurate guidance for structural calculations. Site-specific soil conditions are determined by a geotechnical engineer as part of the development of each project.

CSU has a seismic emergency response protocol that was adopted in 2000 based on efforts of the Seismic Peer Review Board established in 1992. CSU Seismic Safety Requirements strive to build and maintain facilities "that provide an acceptable level of earthquake safety for students, employees and the public." The Seismic Review Board is comprised of seven independent engineers (six structural and one geotechnical) who review and advise CSU of existing policy and code requirements. The six structural engineers are assigned specific campuses and have developed a base of knowledge about each campus, site-specific soil issues, and fault proximity.

The Seismic Policy includes provisions for emergency response by the Seismic Review Board in the event of a significant seismic event. The Chairman of the Seismic Review Board acts as the Designated Building Official for the purposes of safety determination of structures. When an earthquake occurs, the Designated Building Official evaluates the safety of buildings on campus and indicates recommendations for engineering investigations to determine the condition of individual buildings.

The CSU Risk Management Authority performs a tri-annual appraisal of approximately 3,000 buildings (\$14 billion approximate value). The appraisal methodology identifies buildings in flood plains and with earthquake exposure.

CSU has funded and implemented \$22.48 million in system-wide seismic retrofit projects between 2005- 2006 and 2009-2010. The Seismic Retrofit Program has another \$503.6 million in projects in the budget for 2010-2011 through 2014-2015.

**University of California System-Wide Seismic Safety Program.**

The University of California (UC) Seismic Safety Program was initiated following the 1971 San Fernando Earthquake, with the governing Board of Regents adopting policies in 1975 calling for acceptable levels of seismic safety. Structural reviews to identify and set priorities for hazard mitigation were initiated in 1978 and continue on an ongoing basis. Each campus is presently working toward completing corrections on all remaining buildings with a seismic rating V and VI.

From 1979 to 2008, seismic retrofit corrective and mitigation work was completed in more than 230 structures (67 percent of buildings needing seismic work), involving 16 million gross square feet. The cost of this work has been approximately \$1 billion (not adjusted for inflation and excluding FEMA funding).

In addition to its academic facilities, UC operates five major medical centers and is the largest public health care provider in the nation besides the federal Veterans Administration. All hospital facilities are being seismically retrofitted in accordance with the Alquist Hospital Seismic Safety Act as part of the seismic retrofit and replacement program.

**Progress Summary 6.E: University of California Retrofits**

**Progress as of 2018:** The University of California is committed to reducing, preventing or eliminating potential risks and impacts of natural and human-caused disasters and keeping campus communities as safe and disaster-resilient as possible. The University of California (UC)'s Seismic Safety Program is an ongoing system-wide structural retrofit program overseen by each campus. Proposed seismic correctional work is coordinated with fire protection, health and safety upgrades, and rehabilitation or renovations for functional and programmatic improvements, and integrated into UC's Capital Improvement Program. From 1979 to 2016, seismic retrofit corrective and mitigation work has been a part of more than 329 structural improvement projects, 247 of which had been completed as of 2013.

Between 1979 and 2010-11, UC invested more than \$4 billion in seismic safety retrofits, hospital replacement, and various seismic hazard mitigation projects. Since 2011, UC has devoted more than \$1.2 billion to projects that included seismic and life-safety corrections work. Major projects include UC Berkeley's Student Union and Memorial Stadium, both of which had major seismic components to their multi-faceted renovations, and projects that involve complete demolition and rebuild, such as the UC Berkeley Tolman Hall seismic replacement project. Furthermore, UC has undertaken at least 39 smaller seismic projects on nine campuses and at three medical centers with total construction costs of \$174 million (excluding "soft costs" such as design and engineering). Seismic hazard mitigation represents the vast majority of all UC investment in hazard mitigation, commensurate with the degree of catastrophic risk.

### Best Practices Highlight 6.C University of California Seismic Mitigation

The University of California (UC) system-wide Hazard Vulnerability Assessment (HVA) initiative completed in 2005 identified catastrophic earthquake as the highest risk threat for most UC campuses and provides the UC system with a road map on how to most effectively rank and manage a wide range of catastrophic risks.

#### “Be Smart About Safety” Program

Since 2008, funding for many campus hazard mitigation projects and programs have been funded through the “Be Smart About Safety” loss prevention program. From 2001 to 2016 “Be Smart About Safety” funded 153 mitigation projects and programs directly related to these threats, returning more than \$12 million to the campus locations to invest in hazard mitigation for all hazard types. The following 14 seismic hazard mitigation projects funded by the “Be Smart About Safety” program have been implemented by the campuses since 2011.

- UC Berkeley non-structural bracing of library shelves
- UC Irvine seismic review of buildings of potential concern
- UC Irvine non-structural bracing of lab equipment
- UC Irvine bracing platform for data center
- UC Irvine seismic isolation platforms for protecting information technology equipment
- UC Irvine non-structural bracing of furniture and equipment
- UC Irvine structural engineering review of theater
- UCLA automatic gas shutoff valve installations
- UCSF non-structural bracing of furniture and equipment
- UCSF non-structural bracing of research equipment
- UC Santa Cruz automatic gas shutoff valve installations
- UC Santa Cruz gas line work enabling automatic gas shutoff valve

#### Systemwide Building Seismic Gas Shutoff Valve Program

The UC Office of the President Risk Services created a campus reimbursement program funded by a policyholder insurance rebate to install seismic gas shutoff valves on natural gas mains outside campus buildings to prevent the possibility of an uncontrolled release of gas into buildings that could lead to catastrophic fire loss. Property loss prevention building evaluations were conducted in 2007-2009 by the insurer’s engineering personnel on all UC buildings with total property value of at least \$10 million.

As part of this engineering assessment, a prioritized list of campus buildings needing shutoff valves was developed based on the likelihood of a gas main leak/break and the severity of impact should that occur. Likelihood was based on seismicity (earthquake zones), whereas the assessment of severity was based on building fire protection (sprinkler systems). Gas main size was also taken into account for both likelihood and severity, as larger gas mains are inherently less flexible and therefore more likely to break during an earthquake, releasing larger volumes of gas into buildings resulting in more severe fire conditions. To date, under this program eight locations have installed valves at a total cost of \$99,481.

#### 7. *Mitigation for Community Colleges*

Up until June 30, 2006, community colleges also had to comply with the Field Act. On and after July 1, 2006, community colleges could choose not to comply with the seismic safety provisions of the Field Act. This change in law was triggered by the passage of Proposition 1D on the November 2006 ballot pursuant to Assembly Bill (AB) 127 (Nunez, Education Code Section 81052) which provided funds for Field Act seismic upgrades.

At this time, no information is available regarding efforts to mitigate known vulnerable community college buildings.

#### 8. *Mitigation for Locally Regulated Essential Services Facilities*

To mitigate the impact of earthquakes on locally regulated essential services facilities, California enacted the Essential Services Buildings Seismic Safety Act in 1986. Pursuant to the act, the Division of the State Architect (DSA)

within DGS adopted regulations that apply to the construction of all new essential services buildings (California Code of Regulations, Title 24, Part 1, Sections 4-201 to 4-249). There are no statewide regulations for evaluating and retrofitting locally regulated essential services buildings that existed prior to 1986 except for unreinforced masonry (URM) buildings in some jurisdictions. Some local governments and state agencies have voluntarily retrofitted or replaced their vulnerable buildings using current design standards such as ASCE41-13.

### *9. Mitigation for K-12 Public Schools*

Since 1933, public schools have been constructed in accordance with the Field Act, which requires thorough reviews of construction plans, strict inspections, and quality control. The Garrison Act of 1939 set the criteria for use or abandonment of pre-1933 school buildings, becoming the first retrofit legislation passed for public schools in California.

In 2002, the Department of General Services (DGS) released a report on a survey of early Field Act buildings that were constructed to regulations that, for certain types of construction, are no longer considered to provide reliable life safety.<sup>119</sup> Survey results include the following:

- 42,000 Field Act building construction projects were submitted to DSA before the major building code changes effective in 1978.
- Buildings built before 1933 were either removed from use or retrofitted by 1976.
- 9,659 buildings (92 million square feet of space) with non-wood construction were constructed prior to 1978 when major changes were made to the Field Act regulations. Of these, 2,122 Category 1 buildings are expected to perform well and achieve life safety and 7,537 Category 2 buildings are not expected to perform as well as Category 1 buildings and will require more seismic evaluations.

In November 2006, Proposition 1D authorized up to \$199.5 million for purposes of seismic repair, reconstruction, or replacement of Kindergarten through 12th grade (K-12) school facilities. By November 2014, \$50.5 million in bond funds had been apportioned to projects, \$6.6 million in projects had received unfunded approval, and there was \$142.4 million remaining in bond authority. As of April 2016, the State Allocation Board, which oversees state bond allocations, reported approximately \$86.2 million in remaining Proposition 1D bond authority. By April 2018, the entire \$199.5 million made available under Proposition 1D had been allocated to projects that had previously received unfunded approval.

At its April 2018 meeting, the State Allocation Board took action to permit remaining unfunded approved projects previously submitted for funding under the Seismic Retrofit Program under Proposition 1D to be considered for funding under Proposition 51. Proposition 51 passed on the November 2016 statewide ballot, authorizing \$9 billion in bonds to fund construction and improvement of K-12 and community college facilities. A portion of Proposition 51 funds are also available for new seismic retrofit projects under the Facility Hardship Program.

DGS's Office of Public School Construction published a Seismic Mitigation Program Handbook in April 2015 to assist school districts in applying for and obtaining "grant" funds for the purposes of performing seismic mitigation work on school facilities. It is intended to be an overview of the program for use by school districts, architects, and other parties interested in how a school district or county superintendent of schools becomes eligible and applies for the different types of available state funding. The Office of Public School Construction, in conjunction with the Department of Education, offers training workshops and training videos that provide planning and technical assistance to potential applicants. These resources are available on the Office of Public School Construction website at: [https://www.documents.dgs.ca.gov/opsc/Resources/SMP\\_Handbook.pdf](https://www.documents.dgs.ca.gov/opsc/Resources/SMP_Handbook.pdf).

The Guide and Checklist for Nonstructural Earthquake Hazards in California Schools is available for download at: [http://www.caloes.ca.gov/PlanningPreparednessSite/Documents/Nonstructural EQ Hazards For Schools July2011.pdf](http://www.caloes.ca.gov/PlanningPreparednessSite/Documents/Nonstructural_EQ_Hazards_For_Schools_July2011.pdf).

<sup>119</sup> California Department of General Services, Division of the State Architect. "Seismic Safety Inventory of California Public Schools." November 15, 2002.

### Progress Summary 6.F: School Retrofit Progress in the Los Angeles Unified School District

**Progress as of 2018:** Second largest in the nation, the Los Angeles Unified School District (LAUSD) enrolls more than 640,000 students in Kindergarten through 12th grade, at over 900 schools, and 187 public charter schools. The boundaries spread over 720 square miles and include the City of Los Angeles as well as all or parts of 31 smaller municipalities plus several unincorporated sections of Southern California.<sup>120</sup>

LAUSD has been systematically reducing the risk to its facilities and students from geologic hazards through an aggressive program to identify and retrofit hazardous structures. The key to this successful program has been the combination of assessing vulnerability of buildings and facilities, building seismic retrofit into the LAUSD Master Plan, and securing funding for improvements from local and state bond measures and federal grants.

Although a great deal of structural and non-structural seismic retrofit was accomplished following the 1994 Northridge Earthquake as part of the disaster recovery process, the passage of Assembly Bill (AB) 300 in 1999 triggered a more comprehensive approach to addressing LAUSD's earthquake risk.

AB 300 required the Department of General Services (DGS) to survey the state's public school buildings (Kindergarten through 12<sup>th</sup> grade) for earthquake safety, and to submit a report of its findings to the Legislature. The DGS report, released in 2002, identified 269 of LAUSD's nearly 13,000 buildings for detailed seismic evaluation.

In 2006, analysis conducted by LAUSD, including site visits and field investigations, identified a total of 667 buildings that warranted seismic evaluation based upon AB 300 criteria and LAUSD's higher standards. Since that time, seismic evaluations have been performed on school buildings found to be the most seismically vulnerable, and projects have been developed to address the buildings determined to be in the greatest need of structural upgrades.<sup>121</sup>

Priorities for seismic retrofit were based on type of construction, age of building, and occupancy, as follows:

- Priority 1 - Most Critical Type Regardless of Fault Presence (26 buildings)
- Priority 1A: Tilt-Up Buildings
- Priority 1B: Non-Ductile Framed Building Types
- Priority 2 - Buildings within 2 Kilometers (km) of an Active Fault (165 buildings)
- Priority 3 - Buildings 2 to 5 km of an Active Fault (223 buildings)
- Priority 4 - Buildings More than 5 km of an Active Fault (253 buildings)

The Seismic Mitigation Plan was integrated into LAUSD's master planning process with other modernization programs, ensuring that seismic mitigation would be built into future building upgrades, and facilitating access to available school construction funds

Funds to implement the Seismic Mitigation Plan were provided through local and state bond measures as well as federal hazard mitigation grant funds. Five local bond measures (Proposition BB, and Measures R, K, Y, and Q) were passed by the required two-thirds vote between 1997 and 2008, authorizing LAUSD to issue more than \$20 billion in bonds for the construction of new schools and the repair and upgrade of existing buildings, including seismic retrofit or replacement.<sup>122</sup>

In addition to local bond funds, statewide Proposition 1D passed in November 2006 authorized up to \$199.5 million for purposes of seismic repair, reconstruction, or replacement of Kindergarten through 12<sup>th</sup> grade school facilities, providing a supplemental source of funding for LAUSD's Seismic Retrofit Program.

Between 2004 and 2018, hazard mitigation grants were provided on a 75/25 percent match basis through the Federal Emergency Management Agency (FEMA)'s Hazard Mitigation Grant Program (HMGP) and Pre-Disaster Mitigation (PDM) program, as shown in Table 6.E.

<sup>120</sup> <https://achieve.lausd.net/about>

<sup>121</sup> <http://www.laschools.org/new-site/ab300/>

<sup>122</sup> <http://www.laschools.org/new-site/legislation-grants-funding/funding-programs>

**Table 6.E: Hazard Mitigation Grant Funded Seismic LAUSD Retrofit Projects**

Program	Year	Amount	Project
Hazard Mitigation Grant Program (HMGP)	2004	\$100,000.00	Hazard Mitigation Plan
Pre-Disaster Mitigation (PDM)	2005	\$2,999,901.00	Seismic Retrofit - Relocatable Classrooms
LPDM	2008	\$999,809.00	Seismic Retrofit Tilt-Up
HMGP	2008	\$3,000,000.00	Seismic Retrofit Tilt-Ups
HMGP	2009	\$2,000,000.00	Seismic Retrofit - 3 Buildings
PDM	2017	\$150,000.00	Hazard Mitigation Plan
PDM	2018	\$2,300,000.00	Seismic Retrofit

### *10. Mitigation for Hospitals*

Since 1973, hospitals have been required to be built to higher standards than other buildings so they can be reoccupied after major earthquakes. However, many hospitals built before 1973 still remain in service, and some of them pose risks to life or are not expected to be available for occupation after future earthquakes. The 1973 Alquist Hospital Facilities Seismic Safety Act (HFSSA) designated the Office of Statewide Health Planning and Development (OSHPD) as the enforcement agency of the HFSSA mandates. OSHPD's primary objective is to safeguard the public health, safety, and general welfare through regulation of the design and construction of healthcare facilities, to ensure they are capable of providing sustained services to the public.

Senate Bill (SB) 1953, enacted in 1994 after the Northridge Earthquake, expanded the scope of the 1973 Alquist Hospital Seismic Safety Act. The law as amended required that: 1) hospital owners survey the earthquake vulnerability of their buildings and submit to OSHPD their seismic evaluations reports as well as their compliance plans no later than January 1, 2001; 2) by 2013, all hospital buildings built before 1973 that pose threat to life be replaced or retrofitted so they can reliably survive earthquakes without collapsing or posing threats of significant loss of life; and 3) by 2030, all hospital buildings be reasonably capable of providing services to the public after disasters. Furthermore, hospitals were required to have the necessary nonstructural components and systems (emergency generator[s], oxygen tanks, etc.) strengthened by 2002 in order to be able to administer adequate and orderly evacuation of patient and staff, if needed. SB 1953 applies to all acute care facilities (including those built after 1973) and affects approximately 3,083 buildings across 423 hospital facilities. State-owned hospitals are exempt from the seismic compliance requirements of HFSSA (SB 1953).

As of August 2016, more than 91 percent of California's acute care hospitals are no longer at significant risk of collapse in a strong earthquake. Between 2002 and 2016, the inventory of buildings at risk of collapse declined from 1,313 to 251.

SB 1661, SB 499, SB 90, and some subsequent bills which were amendments to the HFSSA, allow hospitals that pose a significant risk of collapse, classified as Structural Performance Category (SPC-1), an extension on the timelines for seismic compliance which could vary from two to up to seven years if progress toward seismic compliance is being made. All SPC-1 hospital buildings must, by 2020 (and in one particular case, by 2022), either be upgraded to SPC-2 (buildings that do not significantly jeopardize life, but may not be repairable or functional after a strong ground motion) or be removed from General Acute Care service. Additional rankings include SPC-3,-4,-4D, and 5, and are largely based on structural capability to provide services following an earthquake and compliance requirements for the January 1, 2030 deadline. SPC-4D is a new Structural Performance Category that is part of the 2016 California Building Standards Code, which allows non-compliant buildings to go past the 2030 seismic compliance deadline. For a detailed list of SPC rankings, please see:

[https://www.oshpd.ca.gov/FDD/seismic\\_compliance/SB1953/SeisPerfRatings.html](https://www.oshpd.ca.gov/FDD/seismic_compliance/SB1953/SeisPerfRatings.html).

For an updated list of hospital SPC rankings in the state, please see: <https://apps.oshpd.ca.gov/fdd/spc.html>.

OSHPD has adopted and enforces regulations for the seismic evaluation and retrofit of existing hospital buildings (see Chapter 6 of the 2016 California Administrative Code and Part 10 of the 2016 California Building Code) that are applicable to all existing acute care hospitals, as well as ASCE41-13 and ASCE/SEI 7-16.

**Table 6.F: Hospital Structural Performance as of December 2017**

Type	Category	Number of Buildings	Percent
Structural Performance Category (SPC)	SPC-1 <sup>a</sup>	200	6.5
	SPC-2	640	20.8
	SPC-3/3s	382	12.4
	SPC-4/4s	805	26.1
	SPC-5/5s	1027	33.3
	Not Assigned	29	0.9
<b>Total SPC Buildings</b>		<b>3083</b>	<b>100</b>
Non-Structural Performance Category (NPC)	NPC-1	170	5.3
	NPC-2	1825	56.7
	NPC-3	235	7.3
	NPC-4	908	28.2
	NPC-5	13	0.4
	Not Assigned	67	2.1
<b>Total NPC Structures<sup>c</sup></b>		<b>3218</b>	<b>100</b>

Source: Office of Statewide Health Planning and Development (OSHPD), [www.oshpd.ca.gov](http://www.oshpd.ca.gov)

<sup>a</sup> SPC and NPC are on a scale where 1 is the most vulnerable and 5 is the least vulnerable

<sup>b</sup> 3s, 4s, and 5s indicate seismic performance ratings self-reported by the hospital and not verified by OSHPD

<sup>c</sup> NPC structures includes tunnels and equipment yards that are not assigned SPC ratings

Table 6.F summarizes the seismic (structural/nonstructural) performance for hospitals. SPC-1 is the most vulnerable ranking for buildings. Many SPC-1 hospitals pose significant collapse risks. SPC-5 hospitals pose the least structural risk.

### *11. Repair of Steel-Frame Buildings*

The cities of Los Angeles and Santa Monica have post-earthquake repair ordinances. Los Angeles required owners to remove the finishes from joints in 242 buildings and repair the ones that were cracked. As of February 2006, the City of Los Angeles has reported cracks repaired in welds in 500 buildings in the region of strongest Northridge Earthquake shaking. The most current recommended evaluation and retrofit provisions are in ASCE/SEI 41-13, Seismic Evaluation and Retrofit of Existing Buildings, FEMA 350 to FEMA 353 and the American Institute of Steel Construction Seismic Provisions (AISC 341). See [www.aisc.org](http://www.aisc.org) for more information.

### *12. Mitigation for High-Rise Buildings*

Guidelines are available for the retrofit of building contents and non-structural building systems, such as ceilings, light fixtures, and mechanical equipment (FEMA 74). Structural retrofits can be accomplished using ASCE/SEI 41-13, Seismic Evaluation and Retrofit of Existing Buildings) or the 2015 or 2018 International Existing Building Code.

The Pacific Earthquake Engineering Research Center (PEER) issued “Guidelines for Performance-Based Seismic Design of Tall Buildings” as part of the Tall Buildings Initiative launched by the cities of Los Angeles and San Francisco in 2010. The 84-page performance-based engineering guide supports design of more economical and constructible future new tall buildings that will perform better during seismic events. To download the guidelines, go to: <http://peer.berkeley.edu/tbi/>.

### *13. Locally Regulated Non-Ductile Concrete Buildings*

#### **Non-Ductile Concrete Building Inventories**

In 2006 PEER was awarded a \$3.6 million grant from the National Earthquake Engineering Simulation Center to assess collapse risks for locally regulated non-ductile concrete buildings and develop enhanced risk management methods.<sup>123</sup> PEER administers the Network for Earthquake Engineering Simulation Grand Challenge project on existing hazardous concrete buildings (NSF Award# CMMI-0402490). The project team completed an inventory of older non-ductile concrete buildings in the City of Los Angeles in 2013, including detailed information on building location, age, configuration, and occupancy.

Prior to this project, this critical information was not available to policy makers, engineers, and researchers in an organized single source. The immediate impact of this inventory was demonstrated as it served as the backbone for earthquake scenario loss studies to help inform the City of Los Angeles on the extent and character of the vulnerability. Laboratory studies have identified critical building components, and earthquake simulation studies have extended those findings to identify building characteristics that make a building most susceptible to collapse. The project is leveraging its work with the Concrete Coalition, FEMA, and National Institute of Standards and Technology (NIST)-funded companion projects to help practicing engineers identify those buildings with highest risk by developing guidelines for assessing vulnerability and methodologies to effectively strengthen the most critical elements that will prevent collapse and save lives.

Under a Hazard Mitigation Grant Program (HMGP) grant, the Concrete Coalition—a network of individuals, governments, institutions, and agencies — has been assessing risks associated with dangerous non-ductile concrete buildings and developing strategies for fixing them. Since 2008, the Concrete Coalition has prepared estimates of the number of pre-1980 concrete buildings in the 22 high-seismic-risk counties in the state.

In 2010, a statewide volunteer effort coordinated by the Earthquake Engineering Research Institute (EERI), through its Concrete Coalition Project, canvassed cities throughout the state to determine how many pre-1980 non-ductile concrete buildings they may have within their jurisdictions. As a result of this effort approximately 16,000 to 17,000 pre-1980 non-ductile buildings were identified in the 22 high risk counties. Not all of these buildings are necessarily dangerous or at risk of collapse. The final report from this phase is available at: <https://www.eeri.org/2011/09/concrete-coalition-california-inventory-project-report-now-available/>.

The next step is to gain a better understanding of which of these represent the highest risk. This is a serious issue for the older, larger cities. San Francisco, for example, has over 3,000 non-ductile buildings. Although many of these will perform adequately in an earthquake, it is important to understand which ones will not and why. The collapse of even one large, high-occupancy building could have devastating consequences for a single community. In 2012-2013, a new phase of the Concrete Coalition work, also supported by an HMGP grant, is focusing on developing tools that help decision-makers understand the dimensions of the problem, as well as help engineers develop techniques to categorize which of these buildings are most vulnerable.

#### **City of Los Angeles Mandatory Non-Ductile Concrete Building Retrofit Program**

In 2016, the City of Los Angeles passed Ordinance 183893, which requires the retrofit of all pre-1977 non-ductile concrete buildings. The goal of the mandatory retrofit program, under the ordinance, is to reduce these structural deficiencies and improve the performance of these buildings during earthquakes. Without proper strengthening, these vulnerable buildings may be subjected to structural failure during and/or after an earthquake.

The City of Los Angeles Department of Building and Safety (LADBS) is in the process of identifying the concrete buildings subject to the retrofit ordinance. Following receipt of an Order to Comply from LADBS, the retrofit program requires owners to take retrofit actions within the following time frames:

- 3 years: Submit a completed checklist for review to determine if the building is a non-ductile concrete building
- 10 years: Submit proof of previous retrofit, or plans to retrofit or plans to demolish the building
- 25 years: Complete construction

<sup>123</sup> <http://peer.berkeley.edu/>

For more information about the City of Los Angeles Mandatory Non-Ductile Concrete Building Retrofit Program, visit the program website: <http://www.ladbs.org/services/core-services/plan-check-permit/plan-check-permit-special-assistance/mandatory-retrofit-programs/non-ductile-concrete-retrofit-program>.

The most current retrofit provisions are available in ASCE/SEI 41-13, Seismic Evaluation and Retrofit of Existing Buildings and in the 2015 and 2018 International Existing Building Codes.

#### *14. Mitigation for Locally Regulated Unreinforced Masonry Buildings*

In 1986, California passed a law requiring local governments in high seismic regions nearest active faults to inventory their URM buildings, establish a risk reduction program, and report to the CSSC. Ninety-three percent of the jurisdictions affected by the URM law comply with its provisions. State government buildings are exempt from the URM law but are partially addressed by other laws and regulations.

In 1990, there were an estimated 30,000 URM buildings statewide; approximately 26,000 were located in Seismic Zone 4 (now called high seismicity regions) with the remainder in Seismic Zone 3 (now called moderate seismicity regions). Ninety-eight percent of the URM buildings in Seismic Zone 4 (high seismicity regions) (283 jurisdictions) have been inventoried and over 70 percent had been retrofitted, demolished, and/or replaced by 2006. Statewide, URM buildings average 10,000 square feet of floor area. Retrofit costs average \$60 per square foot with a range of \$10 to \$150 per square foot.

The CSSC stopped tracking retrofit progress in 2006 for four reasons: 1) budget priorities were established by the Seismic Safety Commission, 2) progress had slowed to the point that changes in overall URM mitigation progress were below 1 percent per year, 3) the costs of the reporting burden imposed on local governments no longer justified the benefits of frequent updates, and 4) Cal OES requests such information through its multi-hazard mitigation program, thus rendering the CSSC's future surveys redundant. An unfortunate result is that most local governments no longer maintain records of their URMs and do not have ready, current, and comprehensive access to that information in the event of damaging earthquakes. The state adopted retrofit standards for URM buildings in Title 24, Part 10 of the 2016 California Building Standards Code. These reference the 2015 International Existing Building Code. Of California's cities and counties, 169 have adopted some form of these standards. See "Status of the Unreinforced Masonry Building Law" (SSC 2006-04) for the mitigation status of each jurisdiction affected by the state's URM law.

A 2016 report published by the California Seismic Safety Commission (CSSC) in partnership with the Pacific Earthquake Engineering Research Center (PEER) found that the City of Napa's program to seismically retrofit URM buildings was successful in reducing damage and the risk to life safety posed by these buildings in the 2014 South Napa Earthquake.

#### **Best Practices Highlight 6.D: URM Retrofit Program Success in San Luis Obispo**

What does it take to make significant hazard mitigation progress? For San Luis Obispo, California, it took the reality of an earthquake 40 miles away and the cooperation of businesses and property owners to make their downtown more resilient. More than 100 unreinforced masonry (URM) buildings have been retrofitted against earthquake forces, largely during the past decade, saving historic buildings, creating downtown vitality, and increasing public safety.

##### **Initial Challenge**

Following adoption of the Unreinforced Masonry Building Law (Alquist) of 1986, City of San Luis Obispo building officials identified 126 hazardous URMs—76 of which were in the downtown core. In 1997 the city's first seismic retrofit ordinance required full strengthening by 2017. By 2004, only 27 of the 127 hazardous buildings had addressed the seismic retrofit requirements.

**San Simeon Earthquake – A Wake-Up Call**

On December 22, 2003, the need for strengthening took on renewed urgency with the Magnitude 6.5 San Simeon Earthquake. The San Simeon Earthquake resulted in two deaths due to URM building collapse and a range of building damage in northern San Luis Obispo County as well as chimney collapses in San Luis Obispo. Recognizing the risk posed to the city's vulnerable buildings, the San Luis Obispo City Council resolved to reassess the effectiveness of the URM ordinance. The San Luis Obispo Chamber of Commerce, tasked with enhancing the economic health of the area, was eager to collaborate with city officials and reconvened its Seismic Task Force, a group including building owners, business owners, and city staff.

**New Ordinance**

In 2004 the 1997 seismic retrofit ordinance was revised to shorten the 2017 deadline to 2010 for completion of all seismic retrofits to hazardous URMs within the city. The Chamber of Commerce pushed for a seismic coordinator who could help its members facilitate plans, engineering, and permits in short order. As part of the 1997 incentive program update, a seismic coordinator was hired who reported to the Economic Development Department overseen by the City Manager. The seismic coordinator had individual contact with every building owner and was responsible for communicating rules and resources via presentations at outreach events and via periodic publications.

**Lessons Learned**

As of 2015, San Luis Obispo has identified five key lessons were learned through this process:

- *Internal Advocate:* Having an internal advocate, the seismic coordinator, made a difference in connecting the people with the law.
- *Willing Players:* Having a few property owners who understood the requirement and made the first step to bring their buildings into compliance got the ball rolling for other building owners.
- *Buy-In from Building Owners:* Working with building owners to achieve understanding and buy-in was essential.
- *Progress-Over-Penalty Approach:* Issuing credits for cooperation was effective in moving many projects forward and enhancing public safety sooner than later.
- *Reasonable Deadlines:* Setting a deadline not too far into the future provided an incentive for work to get done without creating a timeline that was impossible to meet.

**Progress as of 2015**

By 2010, San Luis Obispo had already seen major URM retrofit progress. As of late 2012 all but 14 of the original 126 buildings had been strengthened. Of these, five retrofit projects were in construction, and eight were scheduled to begin construction in 2013, subject to a new deadline of July 1, 2015. As of late 2015, all but eight of the original 126 buildings had been strengthened. Of the eight remaining buildings, two are partially retrofitted and six are under construction.

*Source: City of San Luis Obispo; Claire Clark and Monica Fiscalini*

**15. Mitigation for Tilt-Up Buildings**

The average size of older tilt-up buildings is 30,000 square feet. Average retrofit costs are \$5 per square foot in 2007 dollars. Many of California's light industrial and commercial properties contain tilt-up buildings or buildings with reinforced masonry or concrete walls with vulnerabilities in connections between walls, roofs, and floors. These buildings pose significant risks of casualties and losses in business continuity and California's market share from earthquake damage.

Current retrofit provisions are available in the 2015 or 2018 International Existing Building Code or ASCE/SEI 41-13, Seismic Evaluation and Retrofit of Existing Buildings. The state also encourages sellers of tilt-up buildings and other vulnerable commercial buildings to disclose to buyers any typical earthquake weaknesses defined in the Commercial Property Owner's Guide to Earthquake Safety. State law encourages the disclosure of earthquake weaknesses in commercial properties at the time of sale.

## 16. Mitigation for “Soft-Story” Buildings

In 2005, the state legislature passed AB 304, which encourages cities and counties to address the seismic safety of soft-story residential buildings and encourages local governments to initiate efforts to reduce the seismic risk in vulnerable soft-story residential buildings. AB 304 requires the seismic retrofit of these buildings to comply with a nationally recognized model code relating to the retrofit of existing buildings or substantially equivalent standards. It replaces the word "reconstruction" with "seismic retrofit" in provisions governing earthquake hazardous building reconstruction and defines seismic retrofit for purposes of provisions governing earthquake protection. “Seismic retrofit” means either structural strengthening or providing the means necessary to modify the seismic response that would otherwise be expected by an existing building during an earthquake, to significantly reduce hazards to life and safety.

The following are hazard mitigation strategies recently undertaken locally for “soft-story” buildings in California.

### **Soft-Story Building Inventories**

The cities of Alameda, Berkeley, Fremont, Oakland, San Francisco, San Leandro, and San Jose, as well as other Santa Clara County cities, in addition to Santa Rosa, Los Angeles, Concord, Rohnert Park, Burbank, Pasadena, Santa Monica, and Santa Barbara, all have either undertaken or are in the process of beginning a soft-story building inventory.

Soft-story inventories in California range from those mandated by ordinance (Alameda, San Francisco, and Los Angeles) to those that are voluntary. Since 2006, hundreds of soft-story buildings have been retrofitted. For example, Los Angeles went from 90 retrofitted buildings in 2006 to over 800 retrofitted soft-story buildings by 2009. There is still work to do, though, as most cities with inventories report thousands to tens of thousands of soft-story units.

In addition, the CEA has applied for several HMGP grants (DR-4344 and DR-4353) to assist homeowners with retrofitting of single-family soft-story buildings in San Francisco and Oakland.

### **San Francisco CAPSS Report**

In 2009, as part of the Community Action Plan for Seismic Safety (CAPSS) in the City and County of San Francisco published “Here Today – Here Tomorrow: Earthquake Safety for Soft-Story Buildings.”

Recommendations in the report pertain to “multi-unit soft-story buildings,” defined as, “wood-frame structures, three stories or more, with five or more residential units, built before May 1973, and having a ‘soft-story’ condition on the ground floor.”

Key recommendations included the following:

- The Department of Building Inspection should establish a program that requires owners of wood-frame buildings built before May 21, 1973 with three or more stories and five or more residential units to evaluate the seismic safety of their buildings and to retrofit them if they are found to be seismically deficient.
- Buildings should be retrofitted to a standard that will allow many of them to be occupied after a large earthquake.
- The City should immediately offer incentives to encourage voluntary retrofits. To get owners moving on making their buildings safer, the City should offer incentives to owners who retrofit, including expediting plan review, rebating permit fees, offering planning incentives, and seeking voter approval of a City-funded loan program.
- The Department of Building Inspection should form a working group to develop a detailed plan to implement the recommended program.

For more information about CAPSS, visit: <http://sfgov.org/esip/capss>.

### Best Practices Highlight 6.E: San Francisco Community Action Plan for Seismic Safety and San Francisco’s Soft Story Ordinance

#### Soft Story Ordinance

On the 107th anniversary of the 1906 San Francisco Earthquake, Mayor Edwin Lee signed into law the Mandatory Seismic Retrofit Program for Soft-Story Wood-Frame Buildings, which will lead to seismic strengthening of several thousand buildings in San Francisco. The new ordinance was approved unanimously by the Board of Supervisors with an 11-0 vote following years of work among City officials, property owners, tenants, and community members to reach a retrofiting plan.

More than 58,000 San Francisco residents live in the estimated 3,000 or more wood-frame soft story buildings that are targeted for seismic retrofit by the soft-story ordinance. These same buildings also house approximately 2,000 businesses with an estimated 7,000 employees. The primary goal of the soft-story ordinance is to protect San Franciscans and the city’s housing stock, thus ensuring more rapid recovery from future earthquakes. The Community Action Plan for Seismic Safety (CAPSS) study showed that the retrofiting of soft-story buildings, as required by the new ordinance, would result in a reduction of earthquake collapse hazards, allowing the city to retain significant amounts of housing stock following a moderate earthquake event (Magnitude 7.2) and shortening the recovery time from such an earthquake. Thus, the ordinance promotes the resiliency goals identified in the Community Safety Element of the San Francisco General Plan. The retrofits will also greatly increase the likelihood that these buildings will remain useable (or “safe enough to stay”) for their residents following a major earthquake (SPUR Safe Enough to Stay/Shelter in Place). Allowing San Franciscans to remain in the city will also greatly ensure and quicken recovery.

The soft-story ordinance expanded the reach of the CAPSS report to apply to wood-frame buildings built before January 1, 1978. These buildings consist of at least two stories over a weak ground-floor level or garage with five or more residential units. The ordinance is now being implemented through The Mandatory Soft Story Retrofit Program (MSSP) which was created in 2013 as a multi-year community-based effort led by the Earthquake Safety Implementation Program and enforced by the Department of Building Inspection to ensure the safety and resilience of San Francisco’s housing stock through the retrofit of older, wood-framed, multi-family buildings with a soft-story condition.

As part of this program, all affected property owners received notices beginning in September 2013 and were required to have submitted their screening forms to the Department of Building Inspection by September 15, 2014. The Department of Building Inspection has achieved over 99 percent response to the program. Buildings that have not complied with this requirement have been placarded and issued Notices of Violation. A Wood Frame Compliance Tier and Timeline was developed with the goal of completing all retrofits by September 2020.

The Mandatory Soft Story Retrofit Program provides a weekly update on the status of properties identified as soft story, including an interactive map of all properties. The updates can be found at <http://sfdbi.org/soft-story-properties-list>.

#### City of Los Angeles’ Mandatory Soft-Story Retrofit Program

In 2016, the City of Los Angeles passed Ordinance 183893, which requires the retrofit of pre-1978 wood-frame soft-story buildings. The goal of the mandatory retrofit program, under the ordinance, is to reduce these structural deficiencies and improve the performance of these buildings during earthquakes. Without proper strengthening, these vulnerable buildings may be subjected to structural failure during and/or after an earthquake.

In early 2016, the Los Angeles Department of Building and Safety (LADBS) began issuing Orders to Comply to the first priority tier of soft-story structures (buildings with 16 or more dwelling units). Second priority structures received orders to complete in late 2016. Orders to Comply will be issued the third priority structures through late 2017. The retrofit program requires that, following receipt of an Order to Comply from LADBS, owners to take retrofit actions within the following time frames:

- 2 years: Submit proof of previous retrofit, or plans to retrofit or demolish

- 3.5 years: Obtain permit to start construction or demolition
- 7 years: Complete construction

A progress-over-penalty approach—issuing credits for cooperation—was effective at moving many projects forward and enhancing public safety sooner rather than later.

For more information about the City of Los Angeles Mandatory Soft-Story Retrofit Program, visit the program website:

<http://www.ladbs.org/services/core-services/plan-check-permit/plan-check-permit-special-assistance/mandatory-retrofit-programs/soft-story-retrofit-program>.

### **Current Soft-Story Retrofit Provisions**

The most current retrofit provisions for soft-story buildings are available in the International Existing Building Code 2015 or 2018 Editions or ASCE/SEI 41-13, Seismic Evaluation and Retrofit of Existing Buildings. Local jurisdictions including the cities of San Francisco and Berkeley have enacted voluntary and mandatory retrofit ordinances. The California Building Code allows these references as acceptable alternatives to existing regulations.

### *17. Mitigation for Multi-Unit Wood-Frame Residential Buildings*

California contains a total of 160,000 apartment buildings with five or more units, according to the California Department of Finance. Approximately 130,000 apartment buildings, including 46,000 soft-story buildings, are in regions of high seismicity. The statewide average is 16 units per building.

## **Progress Summary 6.G: California Residential Mitigation Program**

### **Progress as of 2018:**

**Adoption of Chapter A3:** In the fall of 2009, the California Earthquake Authority (CEA) held scoping sessions in Sacramento, Los Angeles, and Oakland to collect informed recommendations from related experts on future opportunities for the seismic retrofitting of residential structures in California. Stakeholders for the CEA mitigation program include California homeowners and renters, the California residential construction industry, the California Governor’s Office of Emergency Services (Cal OES), the Association of Bay Area Governments, the Southern California Association of Governments, the California Seismic Safety Commission (CSSC), Earthquake Country Alliance, and others. The participants at the scoping sessions suggested that a statewide standard was needed. The CEA subsequently worked with the Office of the Governor, Department of Housing and Community Development, CSSC, and California Building Standards Commission to facilitate the August 16, 2010 adoption of the first California Building Code for existing residential structures (Appendix A3 of the 2009 International Building Code -- "Prescriptive Provisions for the Seismic Strengthening of Cripple Walls and Sill Plate Anchorage of Light Wood-Frame Residential Buildings"). The current provisions are found in the 2016 California Existing Building Code.

**Establishing the California Residential Mitigation Program:** In August 2011, the CEA and the California Emergency Management Agency (CalEMA) (now Cal OES) entered into a joint powers agreement to create the California Residential Mitigation Program (CRMP) to carry out a joint mitigation program. The board of directors of the CalEMA/CEA Joint Powers Agreement (JPA) manages the CRMP, which has been designed to provide financial incentives to homeowners who complete seismic retrofit projects on their dwellings. Buildings retrofitted through the CRMP are required to be code-compliant and pass local building department inspections.

**Earthquake Brace+Bolt:** The CRMP piloted the Earthquake Brace+Bolt (EBB) program in 2013, providing up to \$3,000 to homeowners who retrofitted their houses in accordance with program rules and the requirements of Chapter A3 of the California Existing Building Code (raised floor with cripple walls less than 4 feet tall, etc.). Areas in Oakland and Los Angeles selected for the pilot were determined using U.S. Geological Survey (USGS) and census data to identify areas of high seismicity that were also dense with houses built before 1979. These houses were built prior to uniform compliance with seismic-related building codes and are at greater risk of collapsing and sliding off their foundations.

The program, available in more than 180 ZIP codes, also allows for the use of Standard Plan Sets A for the Bay Area and Los Angeles. The CEA estimated that, as of mid-June 2018, more than 5,000 houses had been retrofitted. The EBB program expects to retrofit an additional 6,000 houses between 2018 and 2021.

By requiring compliance with Chapter A3 the goal was, and is, to:

- Strengthen cripple walls to enable them to function as shear members, significantly protecting the dwelling from collapsing;
- Bolt sill plates to the foundation, enabling the dwelling to remain in place rather than sliding off the foundation during an earthquake; and
- Properly strap the water heater to reduce the likelihood of water and fire damage, and to protect the water supply.

Initial funding for EBB was provided through the CEA Loss Mitigation Fund (LMF). The CEA funds LMF through interest earned from CEA investments equivalent to 5 percent (not to exceed \$5,000,000) annually. Additional funding was provided by the State of California in the amount of \$3,000,000 in 2016, and again in 2017. These funds were distributed through the California Department of Insurance. The CRMP sought and received \$300,000 in Federal Emergency Management Agency (FEMA) Hazard Mitigation Grant Program (HMGP) funds to establish an EBB program in Napa. The CEA has applied for additional FEMA funding through HMGP for DRs 4308, 4344, and 4353. If these grants are awarded, EBB could receive between \$3 million and \$28 million to retrofit single-family, wood-framed dwellings and an additional \$5 million to \$15 million to retrofit soft-story dwellings in San Francisco and Oakland.

Homeowners seeking to participate in EBB must meet specific program requirements including living in a program ZIP code and providing receipts and documentation of the retrofit and a copy of a building permit approving and signifying that the retrofit was done in accordance with the current building code.

Since 2013, the CRMP has issued grants to over 5,000 homeowners. The program will continue as long as funding is available. EBB has the potential to expand the types of houses that can participate in the program as additional engineered prescription solutions become available and codified. Additional information on EBB can be found at: [www.earthquakebracebolt.com](http://www.earthquakebracebolt.com).

### *18. Mitigation for Single-Family Wood-Frame Dwellings*

A 1999 survey by the Association of Bay Area Governments (ABAG) determined that from 2 percent to 38 percent of Bay Area homes were retrofitted depending upon jurisdiction, with an average retrofit rate well below 10 percent. Similarly, the California Earthquake Authority (CEA) has found that about 6 percent of policyholders have retrofitted their homes.

The following cities have voluntary dwelling retrofit programs:

- Los Angeles – 6,000 dwellings retrofitted as of February 2006 (also adopted a voluntary hillside dwelling retrofit ordinance)
- Berkeley
- San Leandro
- Oakland
- Santa Barbara
- Santa Monica

The most current retrofit provisions are available the 2018 International Existing Building Code. Local governments in the San Francisco Bay region have adopted more stringent retrofit provisions called Standard Plan Set AA. The City of Los Angeles also has an approved Plan Set (LA Standard Plan Set No. 1) for the retrofit of single-family wood-frame dwellings.

The state also requires sellers of dwelling buildings to disclose to buyers any typical earthquake weaknesses defined in the Homeowner’s Guide to Earthquake Safety

**Best Practices Highlight 6.F: Mitigating Seismic Vulnerability of Housing**

**Residential Hazard, Vulnerability, Risk, and Mitigation Assessment  
Role of California Earthquake Authority (CEA)**

**Seismic Vulnerability of Statewide Housing Stock**

Approximately 38 million people reside in California in approximately 14 million residential units (see Table 6.G). Housing represents the largest class of occupied buildings in the state. The majority of Californians live south of the Tehachapi Mountains or in the San Francisco Bay Area. Both areas have numerous extensive faults running through and near them and are subject to strong levels of earthquake shaking potential. It is generally acknowledged that inadequately constructed and/or maintained buildings, situated on poorly performing soils, tend not to perform well during earthquakes. A statewide study of the performance of the California residential building stock has never been conducted. Studies of residential units, in general, have been localized and completed only after earthquakes have occurred.

Several studies of earthquake effects on housing have been completed, including those associated with the San Francisco Bay Area and the Los Angeles metropolitan area in 2007 and 2008 through the Community Action Plan for Seismic Safety (CAPSS) program in the San Francisco Bay Area and the Great California ShakeOut drills in 2008 and 2009. For a detailed discussion of the Great ShakeOut, see [Section 6.1.3](#).

Residential construction increasingly has been influenced by natural hazard issues in California. Faulty performance of building stock during earthquakes has required numerous changes in building codes affecting subsequent construction, design, practices, and materials used. To date, neither a statewide assessment of California residential building stock nor statewide tracking of completed seismic retrofitting of housing has been funded or completed in California. Therefore, the losses that could be avoided by the seismic retrofitting of residential units have not been calculated or otherwise determined. The availability of this information would be useful in the development of future earthquake mitigation activities and could be an area of ongoing surveillance and study should the Federal Emergency Management Agency (FEMA) decide to pursue it.

Table 6.G identifies the numbers and percent of housing units in California by type. It indicates that a majority of units (57.8 percent) are single-family detached.

**Table 6.G: California Housing Units by Type, 2017**

Units in Structure	Number of Units	Percent of Total
1 unit detached	8,128,817	57.8%
1 unit attached	980,957	6.9%
2 to 4 units	1,126,344	8.0%
5+ units	3,273,164	23.2%
Mobile homes	561,586	3.9%
<b>Total housing units</b>	<b>14,070,868</b>	<b>100%*</b>

Source: Table E-5, County/State Population and Housing Estimates, State of California, Department of Finance, January 1, 2017.

\* Percentages do not add to 100% due to rounding

**Impediments to Seismic Hazard Mitigation for Housing**

The following are potential impediments to seismic hazard mitigation for residential units, along with actions being taken or needed to overcome these impediments:

*1. Lack of Standardization.* Seismic retrofits standards, specifications, and plans have generally not been standardized and included in the California Existing Building Code. The CEA recently worked with the Office of the Governor, Department of Housing and Community Development, California Seismic Safety Commission, and California Building Standards Commission to adopt (on August 16, 2010) the first California Existing Building Code for the seismic retrofitting of wood frame dwellings: 2009 International Existing Building Code Appendix Chapter A3—Prescriptive Provisions for the Seismic Strengthening of Cripple Walls and Sill Plate Anchorage of Light, Wood-Frame Residential Buildings—by amending the 2010 and 2013 California Existing Building Code) for existing residential structures.

The CEA has since joined forces with the Federal Emergency Management Agency (FEMA) to develop comprehensive guidelines for evaluating and seismically retrofitting single-family dwellings. These guidelines will include additional prescriptive provisions for certain earthquake deficiencies in single-family dwellings (such as cripple walls greater than 4 feet in height and dwellings with a living space over a garage) as well as detailed provisions for use by registered design professionals. The CEA has also begun a research program seeking to determine the percentage of damage that may be reduced if the seismic/structural retrofitting of a house is done correctly. Considering its present form, the California Building Code may require revisions to determine whether a seismic retrofit of a 1- to 4-family residence should also trigger other, unrelated code-upgrade requirements.

*2. Need for Training.* Building officials need to be trained to identify and evaluate seismic retrofit standards, specifications, and plans. Building contractors and related craftspeople also need to be trained to understand standards, specifications, and plans in order to successfully install the seismic retrofits into existing 1- to 4-family residences. The CEA is requesting that the Federal Emergency Management Agency and the International Code Council update their respective training materials to incorporate the new California Existing Building Code adopted in January 2017 for the seismic retrofitting of residential structures.

### **Statewide Initiatives for Mitigating the Effects of Seismic Hazards on Housing**

At present, aside from the state’s property tax reappraisal exclusion and tax credits for nationally registered historical homes, the only other statewide seismic hazard mitigation incentives for residences are related to those offered by residential earthquake insurance providers.

In 2018, the CEA is the largest provider of earthquake insurance in California and has more than \$15 billion in claim-paying capacity. The CEA is privately financed through insurance premiums and is a publicly managed instrumentality of the state. Private insurers that write residential property insurance in California may, at their option, and upon meeting participation requirements, participate in the CEA. Once they become CEA participants, insurers no longer write residential property earthquake insurance coverage and instead satisfy their legal obligation to offer earthquake insurance to their residential property policyholders by offering a CEA policy. Insurers that participate in the CEA are referred to as “Participating Insurers.”

The CEA has maintained an A.M: Best Company financial-strength rating of “A minus (Excellent)” since 2002. The CEA is working with the California Governor’s Office of Emergency Services (Cal OES) to distribute financial incentives to homeowners to help offset the cost of residential structural retrofits.

Under California law, the CEA is required to offer a mitigation discount on an insured’s CEA earthquake insurance annual premium if an insured has met certain mitigation criteria. Not all houses qualify for this discount. Section 10089.40(d) of the California Insurance Code describes the minimum effort needed for a CEA policyholder of a residential dwelling to qualify for a 5-percent premium discount.

Current requirements for qualifying for the premium discount are:

- Dwelling was built prior to 1979
- Dwelling is tied to its foundation
- Dwelling has cripple walls braced with plywood or its equivalent
- Water heater is secured to the building frame

The same code section states, “The CEA Governing Board may approve a premium discount or credit above 5 percent, as long as the discount or credit is determined actuarially sound by the authority.”

In January 2016, CEA introduced discounts of up to 20 percent for properly retrofitted older houses. A 23 percent discount, on average, is available for mobile homes reinforced by an earthquake-resistant bracing system certified by the California Department of Housing and Community Development.

CEA enabling legislation calls for mitigation activities, including research, development, and consumer education, as well as contents mitigation and structural retrofitting. The CEA is continuing to work with stakeholders to determine how to specifically approach the seismic retrofitting of residential structures. For a discussion of this initiative, see Progress Summary 6.G.

### **Residential Earthquake Insurance as a Loss Reduction Tool**

Depending on the homeowner’s earthquake insurance provider, the successful utilization of the seismic retrofit standards and general plans may be considered when awarding discount points to homeowners to lower their earthquake insurance premiums. It is anticipated that the resiliency added to correctly retrofitted homes will help lower the potential for loss of life, injury, and structural and non-structural damage as well as contents damage resulting from earthquakes. The impact on mitigation activity levels and the benefits gained from incentives such as lowering residential earthquake insurance premiums for seismically retrofitted housing units are unknown.

### **Non-Structural Mitigation Items Provided to Californians by the CEA**

The CEA has provided funding to help the U.S. Geological Survey (USGS) and other agencies jointly develop and publish several guides on earthquake safety and preparedness, including “Staying Safe Where the Earth Shakes,” which covers 57 counties and replaced “Putting Down Roots in Earthquake Country,” which covered Southern California and the Bay Area, and “Living on Shaky Ground,” which covers the North Coast Region. Other guides on home earthquake safety and preparedness include the California Seismic Safety Commission’s “Homeowner’s Guide to Earthquake Safety”, and “Improving Natural Gas Safety in Earthquakes.”

The CEA also has an ongoing hazard mitigation-funding program. The CEA’s commitment to mitigation is reflected in its Strategic Plan adopted by the CEA Governing Board in 2003. The plan calls for the CEA to “educate residents about their earthquake risk and motivate them to protect themselves and their property.” The CEA board sets aside funding each calendar year (equal to 5 percent of its investment income, up to \$5 million annually) for funding mitigation. This annual allocation requirement is set forth in California Insurance Code Section 10089.37. The CEA also has raised more than \$1 million for the American Red Cross to support disaster-relief efforts and assist communities in preparing for disasters.

### Progress Summary 6.H: Seismic Evaluation of Single-Family Dwellings

**Progress as of 2018:** The California Earthquake Authority (CEA) has joined forces with the Federal Emergency Management Agency (FEMA) to develop comprehensive guidelines for evaluating and seismically retrofitting single-family dwellings. These guidelines will include additional prescriptive provisions for certain earthquake deficiencies in single-family dwellings (such as cripple walls greater than 4 feet in height and dwellings with a living space over a garage) as well as detailed provisions for use by registered design professionals. The CEA also began a research program seeking to determine the percentage of damage that may be reduced if the seismic/structural retrofitting of a house is done correctly. Considering its present form, the California Building Code may require revisions to determine whether a seismic retrofit of a one to four-family residence should also trigger other, unrelated code-upgrade requirements.

With the publication of the Simplified Seismic Assessment of Detached, Single-Family, Wood-Frame Dwellings (FEMA P-50) in 2012, FEMA provided home inspection and retrofit professionals with methods to assess seismic and structural vulnerabilities of an individual house and assign a Seismic Performance Grade for the dwelling and identify portions of the dwelling in need of retrofit. Seismic Retrofit Guidelines for Detached, Single-Family, Wood-Frame Dwellings (FEMA P-50-1) includes specific guidance for retrofitting a dwelling's seismic deficiencies (identified using the FEMA P-50 Simplified Seismic Assessment Form) and potentially improving its Seismic Performance Grade.

The CEA, a contributing partner in the development of the documents, began coordinating trainings in use of FEMA P-50, covering expenses in part with National Earthquake Hazards Reduction Program (NEHRP) funding. Since 2015, over 250 seismic inspection professionals have completed the training.

In an effort to build a cadre of inspection professionals proficient in use of FEMA P-50, the CEA collaborated with the California Real Estate Inspection Association to develop the Simplified Seismic Assessment Certification. With the assistance of Applied Technology Council (ATC) a training program is under development with plans to implement in 2018.

In 201, the CEA developed a web-based application based upon the FEMA P-50 Simplified Seismic Assessment Form. QuakeGrade™ is available on mobile devices (smart phones and tablets), laptops, and desktop computers. Hazard scores for shaking, fault rupture, landslide, and liquefaction risks are automatically calculated using real time data from the U.S. Geological Survey (USGS) and California Geological Survey (CGS). The resulting report identifies structural vulnerabilities with retrofit potential in an easy to understand format for homeowners. While the assessment is “simplified” it does require comprehensive knowledge and understanding of structural components of detached, single-family, wood-frame dwellings. Because of this, CEA limits access to the application to licensed and certified inspection professionals only.

#### *19. Mitigation for Mobile/Manufactured Homes*

In 1983, the state began to regulate the design and construction of optional Earthquake-Resistant Bracing Systems (ERBS) that can be installed under existing mobile/manufactured homes at the owners' discretion. When properly installed, ERBS are intended to resist seismic forces and vertical movement of mobile/manufactured homes.

Foundation system requirements for mobile homes, similar to wood-frame dwellings, to reduce or prevent collapse during an earthquake event include the following:

- Earthquake-Resistant Bracing Systems (ERBS)
- Engineered tie-down systems (ETS)
- Reinforced concrete or reinforced masonry foundation

ERBS installed in California mobile homes must be certified and comply with California code.<sup>124</sup>

<sup>124</sup> CA Adm. Code, Title 25, Chapter 2, Art. 7.5.

Other recommended retrofits of mobile homes include bracing water heaters and installing a flexible connector from gas meters and automatic gas shutoff devices.

The California Department of Housing and Community Development (HCD), Division of Business, Consumer Services and Housing oversees the Mobile Home Parks Program, funded by the Mobile Home Parks Special Occupancy Parks Revolving Fund, which has statewide jurisdiction over manufactured/mobile home installations and park construction and investigates health and safety inquiries. Since 1994, the Mobile Home Parks Program has permitted installation or reinstallation of approximately 65,800 units with the state engineered tie-down systems, or other approved systems, to resist horizontal and/or vertical loads.

### Progress Summary 6.I: Mobile Homes

**Progress as of 2018:** Regulations that became effective April 1, 2013, now apply the current California Residential Code structural standards to any alteration of a mobile/manufactured home built after 1958. Previously, there were no structural requirements for mobile homes built between 1958 and 1971. This will add to the structural and lateral stability of mobile/manufactured housing when altered, modified, or converted.

In 2015, Cal OES worked with FEMA and EERI to create an informational guide on methods for seismic retrofit of mobile homes. This flyer was translated into Spanish in 2016. To download the two-page guide visit the Cal OES webpage: <http://www.caloes.ca.gov/EarthquakeTsunamiVolcanoProgramsSite/Documents/Mobile-Homes-in-Earthquakes.pdf>.

## 20. *Mitigation of Losses in Non-Structural Systems*

### Overview

California did not begin to regulate the earthquake safety of non-structural systems in buildings, such as water heaters, ceilings, light fixtures, and heating equipment, until the 1970s. Buildings built before the 1970s and newer buildings that were not regulated and that have unbraced systems can be made safer with retrofit or replacement projects. FEMA offers guidelines for the evaluation and retrofit of building contents and non-structural building systems (FEMA 74). These retrofits can significantly reduce the risks of injuries and business interruption from earthquakes and are often feasible at very low costs.

Cal OES offers guidelines for evaluating and retrofitting non-structural falling hazards common to schools at: [www.caloes.ca.gov](http://www.caloes.ca.gov). The Homeowner's Guide to Earthquake Safety and the Commercial Property Owner's Guide to Earthquake Safety also contain recommendations on how to identify and retrofit contents and non-structural systems in buildings that are vulnerable to earthquakes. In addition, the "Dare to Prepare" campaign of the Earthquake Country Alliance website, <http://www.daretoprepare.org/>, has information for securing non-structural items. Water heater bracing kits that are certified for use by the Division of the State Architect are available at most hardware stores. The Division of the State Architect also offers seismic strapping instructions on its website, at [www.dgs.ca.gov/dsa/Resources/pubs.aspx](http://www.dgs.ca.gov/dsa/Resources/pubs.aspx). Since 2014, Cal OES Earthquake Program has partnered significantly with QuakeSmart, a National Earthquake Hazards Reduction Program (NEHRP) funded mitigation education program for business to create online materials encouraging non-structural mitigation for businesses and organizations. Based on a Cal OES Earthquake Program priority, QuakeSmart partnered with the Los Angeles County Fire Department to pilot a voluntary non-structural assessment program, delivered by the fire department as part of annual business fire inspections.

Bracing can prevent fires and serious water damage caused by toppled water heaters. State law requires all replacement water heaters to be braced and all existing residential water heaters to be braced upon sale of buildings (Health and Safety Code Section 19210, et seq). For more information on seismic hazard risks from non-structural building components, visit:

[http://www.caloes.ca.gov/PlanningPreparednessSite/Documents/Nonstructural EQ Hazards For Schools July2011.pdf](http://www.caloes.ca.gov/PlanningPreparednessSite/Documents/Nonstructural_EQ_Hazards_For_Schools_July2011.pdf).

### Mitigation of Natural Gas Systems in Buildings

The CSSC has developed guidance for local governments for mitigating natural gas systems in buildings, titled Improving Natural Gas Safety in Earthquakes (SSC 02-03). The most cost-effective mitigation method is training the public to know when and how to manually shut off existing gas valves. Table 6.H shows local governments that have adopted mandatory seismic gas shutoff valve ordinances.

**Table 6.H: Seismic Gas Shutoff Valves Ordinances**

Jurisdiction	Ordinance Number(s)	Year(s) Adopted
Los Angeles <sup>a</sup>	171874, 174343	1995, 1998, 2002
Martinez	1269	1999
Contra Costa County	2000-11	2000
Richmond	32-00	2000
Alameda County	02001-54, 0-2001-55	2001
Marin County	322	2001
Hercules	9-2.09	2001
West Hollywood	01-592	2001
Brentwood	715	2002
Concord	02.9	2002
Danville	2007-08	2007

Source: California Seismic Safety Commission

<sup>a</sup> Los Angeles installed 168,000 valves as of February 2006

[https://ssc.ca.gov/forms\\_pubs/cssc\\_2002-03\\_natural\\_gas\\_safety.pdf](https://ssc.ca.gov/forms_pubs/cssc_2002-03_natural_gas_safety.pdf)

### 21. Mitigation of Fires Following Earthquakes

A general framework for fire mitigation includes the following components provided in advance of an earthquake disaster: 1) reduction in damage through advance planning and preparation; 2) presence of functioning automatic sprinklers or other suppression systems; 3) citizens able to extinguish the fire if water is available or to call the fire department; 4) functioning communications (i.e., telephone) required to contact fire departments; 5) available fire department personnel and their assets (i.e., apparatus); 6) functioning transportation networks (i.e., roads); 7) an adequate water supply; and 8) advance provision of firebreaks, via the urban planning process.

In addition, mitigation for the prevention of natural gas system leakage has included localized upgrading of natural gas pipelines and automatic seismic shut-off switches that cut off natural gas to customers. It is critical that restoration of gas service following an earthquake be coordinated through the local gas utility and the fire department to ensure that service is not restored until leak detection and minimum safety requirements are met on the distribution side of the gas meter. Restoration of gas and electrical services for areas known or suspected to have sustained damage may not occur until the utilities and the fire department are prepared to have service restored.

An additional mitigation technique is the use of seismic pressure wave-triggered automatic garage door openers and alarms at fire stations. These devices help ensure that firefighters and fire equipment are not trapped in damaged fire stations following earthquakes.

## 6.1.5.3 EARTHQUAKE MITIGATION FOR LIFELINE INFRASTRUCTURE

### 1. Mitigation for Electrical Utilities

The California Public Utilities Commission (CPUC) mitigates geologic hazards to electric infrastructure in California through its role in permitting electric infrastructure projects, including transmission and substation facilities. CPUC staff oversee the development of environmental documents in accordance with the California Environmental Quality Act (CEQA). Among other elements, CEQA requires each project to be assessed in relation to potential impacts from geology and soils-related hazards. Included are potential exposure of people or structures to earthquake fault rupture, strong seismic ground shaking, and ground failure including liquefaction, landslides and landslide

susceptibility, lateral spreading, subsidence, expansive soils, and soil erosion. The CPUC website contains a listing of current and past projects, including those that have been approved or denied. Additional information may be found at <http://www.cpuc.ca.gov/ceqa/>.

## 2. *Mitigation for Pipeline Networks – Oil and Natural Gas*

Pipelines subjected to significant displacement may develop leaks or breaks. These may be caused by ground deformation or by strong ground shaking. Ground deformation may include fault rupture as well as landslides, liquefaction, or subsidence. Typical mitigation measures to offset this vulnerability include assessing siting requirements, flexible couplings, and aboveground fault crossings. Mitigation for fault crossings may also be accomplished by making pipes flexible enough and pipe supports big enough to allow pipelines to move to accommodate the anticipated ground displacements without rupture. Seismic mitigation for pipeline supports may also include reducing friction at pipe supports.

Mitigation of areas prone to landslides prior to installation or rerouting of pipelines is possible. Ground deformation can cause significant damage to older pipe works made of cast iron or clay. For more discussion of natural gas pipeline hazards, see [Chapter 9, Section 9.2.3](#).

In recent years, several natural major water supply pipeline replacement projects have been undertaken in California. These projects tend to focus on replacing older pipes, valves, and pumps in an effort to maintain the reliability and modernize systems. For example, the East Bay Municipal Utility District (EBMUD) recently completed a \$662 million Seismic Improvement Program. The San Francisco Public Utilities Commission (SFPUC) is in process on a water system improvement program to be completed in 2019.<sup>125</sup> This program includes a Bay Tunnel project to improve reliability of water delivery against earthquake hazards; see Best Practices Highlight 6.G.

### **Best Practices Highlight 6.G: San Francisco Public Utilities Commission’s Water System Improvement Program**

A large portion of the damage in San Francisco during the 1906 San Francisco Earthquake resulted from subsequent fires burning unchecked across the city due to broken water mains preventing firefighters from extinguishing fires. Today it is understood that keeping critical water supplies and other utilities functional following a major earthquake is essential to preventing cascading hazards, such as fire, from causing additional damage.

The San Francisco Public Utilities Commission (SFPUC) manages over 1,200 miles of pipes that deliver Hetch Hetchy water to San Francisco and other cities in the region, serving more than 2.6 million Bay Area residents. Since 2003, the SFPUC has been at work on a \$4.8 billion program to renovate the aging Hetch Hetchy water system, following approval of a bond measure approved by San Francisco voters in November 2002. The project, called the Water System Improvement Program (WSIP), will be paid for by retail customers in San Francisco, as well as 26 wholesale customers serving Alameda, San Mateo, and Santa Clara Counties. The program features a total of 83 projects, 35 of which are within San Francisco and the other 48 of which are regional projects spread over seven counties.

The objectives of the WSIP include the following:

- Improve the system to provide high-quality water that reliably meets all current and foreseeable local, state, and federal requirements
- Reduce vulnerability of the water system to damage from earthquakes
- Increase system reliability to deliver water by providing the redundancy needed to accommodate outages
- Provide improvements related to water supply/drought protection
- Enhance sustainability through improvements that optimize protection of the natural and human environment

As of June 30, 2016, the WSIP is approximately 91 percent complete, with construction finished on 35 local projects and 37 regional projects in the Hetch Hetchy water system. Work is underway on eight regional projects valued at \$2.1 billion, while construction has been completed on 37 regional projects valued at \$1.6 billion. Only one regional project—the Alameda Creek Recapture Project—remains in pre-construction.

<sup>125</sup> [www.SFWater.org](http://www.SFWater.org)

The draft environmental impact report (EIR) for this project is scheduled to be released November 30, 2016, with an anticipated certification in June 2017.

The eight regional WSIP projects underway as of June 30, 2016 are:

- *Alameda Creek Recapture Project (ACRP)*: This project, still in the pre-construction phase, will recapture water released and bypassed at Calaveras Dam and the Alameda Creek Diversion Dam and return it to the SFPUC water system.
- *Bioregional Habitat Restoration*: In accordance with the objective for sustainability and protection of the natural environment, this project will provide a coordinated and consolidated approach to compensate for habitat impacts that result from implementation of the WSIP projects.
- *Calaveras Dam Replacement*: This project includes the replacement and relocation of the existing, seismically unsafe dam with a new dam located downstream. The new dam will restore the reservoir water storage to its original capacity.
- *Fish Passage Facilities within Alameda Creek Watershed*: This project will upgrade the existing Alameda Creek Diversion Dam with a new fish passage and stream diversion facilities.
- *New Irvington Tunnel*: The new tunnel will run parallel to the existing tunnel and will include connections for the Alameda Siphons and Bay Division Pipeline.
- *Peninsula Pipelines Seismic Upgrade*: This project includes seismic upgrades of three Hetch Hetchy regional water delivery pipelines located in San Mateo County.
- *Regional Groundwater Storage and Recovery*: This project will balance the use of both groundwater and surface water to increase supply reliability during dry years or in emergencies.
- *Seismic Upgrade of Bay Division Pipeline Nos. 3 and 4*: This improvement project will address seismic system vulnerabilities in the vicinity of the Hayward Fault.

The program is expected to be completed in full by the spring of 2019, after the 18-month construction period of the Alameda Creek Recapture Project. More information about the program can be found at: <http://www.sfwater.org/index.aspx?page=114>.

The California Public Utilities Commission (CPUC) ensures that intra-state natural gas and liquid petroleum gas pipeline systems are designed, constructed, operated, and maintained according to safety standards set by the CPUC and the federal government. The CPUC enforces natural gas and liquid petroleum gas safety regulations; inspects construction, operation, and maintenance activities; and makes necessary amendments to regulations to protect and promote the safety of the public, the utility employees that work on the gas pipeline systems, and the environment. This includes reviewing each project for compliance with CEQA requirements. The CPUC also conducts audits and inspections of gas facilities owned and operated by mobile home parks and conducts inspections of propane gas pipeline distributions systems.<sup>126</sup>

Intra-state hazardous liquid pipelines are regulated by the Office of the State Fire Marshall (OSFM). Interstate pipelines are regulated by the Pipeline and Hazardous Materials Safety Administration (PHMSA). For additional details, see [Section 9.2.3: Natural Gas Pipeline Hazards](#) and [Section 9.2.2: Oil Spills](#).

### 3. *Mitigation for Petrochemical Facilities: Oil Refineries and Liquefied Natural Gas Facilities*

The following guidelines and California Building Code provisions address seismic hazards in petrochemical facilities:

- Guidelines for Seismic Evaluation and Design of Petrochemical Facilities by the American Society of Civil Engineers (ASCE)
- Marine Oil Terminal Engineering and Maintenance Standards (MOTEMS) by the California State Lands Commission (CSLC) Marine Environmental Protection Division, which is codified as California Code of Regulations Title 24, Part 2, California Building Code, Chapter 31F – Marine Oil Terminals

<sup>126</sup> [www.CPUC.ca.gov](http://www.CPUC.ca.gov)

Both documents contain general seismic hazard assessment and mitigation for design information. The Guidelines for Seismic Evaluation and Design of Petrochemical Facilities provide information for engineers to develop project-specific seismic hazard mitigation designs and also contain information for emergency contingency planning, post-earthquake damage assessment and seismic retrofit design.

Liquefied natural gas facilities follow the National Fire Protection Association (NFPA) 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas, which has very specific and detailed guidelines on seismic design.

### Application of MOTEMS

The California State Lands Commission (CSLC) regulates all (approximately 34) marine oil terminals in California, including enforcement of state building standards. Most marine oil terminals in California were built in the early 1900s when oil was carried by ships much smaller than the size of today's tankers, and before modern seismic safety standards and environmental review requirements were established.

The Marine Oil Terminal Engineering and Maintenance Standards, known as MOTEMS, are rigorous building standards adopted to upgrade aging terminals and design new terminals to ensure better resistance to earthquakes, protect public health and the environment, and reduce the potential of an oil spill. The MOTEMS, as part of the 2016 California Building Code (California Code of Regulations, Title 24, Chapter 31F et. seq), apply to all marine oil terminals in California and establish minimum engineering, inspection, and maintenance criteria for marine oil terminals to protect public health, safety, and the environment.

The MOTEMS are one of the only comprehensive engineering standards for marine structures in the industry. The MOTEMS are thus frequently applied to marine and waterfront facilities worldwide, regardless of whether the facilities transfer oil, are located in California, or are within the CSLC's jurisdiction. Many standards, guidelines, and other applications also reference versions of the MOTEMS in part or whole.

### **Progress Summary 6.J: Marine Oil Terminal Engineering and Maintenance Standards (MOTEMS) Audit Manual**

**Progress as of 2018:** The Marine Oil Terminal Engineering and Maintenance Standards (MOTEMS) require that operators of marine oil terminals conduct periodic audits and inspections, both above and below the water line, to assess structural and non-structural systems integrity. These audits and inspections involve structural, seismic, geotechnical, mooring, berthing, fire protection, pipeline/piping, mechanical, electrical, and corrosion evaluations.

The MOTEMS Audit Manual was developed to help marine oil terminal operators conduct audits to comply with the 2016 MOTEMS. The manual provides a structured template for methodically documenting a marine oil terminal's characteristics and assessing compliance during MOTEMS audits. The manual is a compilation of 11 checklists, one for each substantive division/section of the MOTEMS. While not required for MOTEMS compliance purposes, these checklists have proven to be useful tools for compliance assessment and communications between terminal owners and operators, MOTEMS audit teams, and the California State Lands Commission (CSLC). The Audit Manual is available through the CSLC website at: [http://www.slc.ca.gov/Programs/MOTEMS\\_More.html](http://www.slc.ca.gov/Programs/MOTEMS_More.html).

### Criteria for Liquid Natural Gas Receiving Terminals

In the last decade, a number of liquid natural gas (LNG) receiving terminals were proposed offshore of the California coast. None of these proposed projects were constructed. The current MOTEMS do not specify any distinctly different requirements for LNG terminals. However, the California State Lands Commission (CSLC) acknowledges that there should be significant differences in the design criteria for LNG terminals because of the hazards involved in handling and transferring LNG between shore and ships. Since 2010, there has been considerable discussion of LNG exports instead of imports as the oil industry is considering possibilities for LNG extraction from shale gas. The CSLC will address the issue of managing LNG hazards as the national policy on LNG export becomes clearer.

Prior to publication of the 2010 SHMP, at a time when LNG receiving terminals were being proposed for California, the development of draft LNG Terminal Engineering and Maintenance Standards (LNGTEMS) was initiated under the direction of the CSLC Marine Facilities Division (MFD). As of November 2011, there were no proposals contemplated for any new LNG terminals in California, and further development of the draft was terminated. The draft set of regulations was not expected to be carried forward because it appeared to be unneeded in California at that time. However, recognizing that the fundamental work may be of value for other states or in other areas of the world where LNG terminal construction is still likely, the CSLC staff released the last draft of LNGTEMS to the public, to serve as a resource for state/federal agencies, terminal operators, and consultants.

#### 4. *Mitigation for Localized Water and Wastewater Pipelines and Treatment Facilities*

One mitigation technique to prevent an effluent discharge due to the loss of power at water and wastewater treatment facilities is to include back up power at such plants to keep facilities operational. See [Annex 3](#) for detailed discussion on lifelines infrastructure and hazard mitigation planning, including water supply infrastructure such as the facilities illustrated in Map 6.R.

Additional mitigation measure that can be taken for these facilities include:

- Seismic retrofit pipes with flexible joints
- Reinforce settling tanks
- Harden or replace transmission lines with earthquake resilient designs
- Secure aboveground pipes
- Install earthquake shutoff valves

Section 15.3 of ASCE 7/NEHRP (National Earthquake Hazards Reduction Program) Recommended Seismic Provisions provides extensive guidance on the design of non-building structures, including water storage tanks, water treatment plants, and pipeline systems.<sup>127</sup>

An article published in the August 2017 issue of Safety Science concluded that additional work is needed to better understand the seismic vulnerability of municipal or industrial wastewater treatment plants and develop new vulnerability functions based on documented damage observations from earthquakes, the article also states that municipal water treatment plants are more vulnerable to earthquakes, and that non-structural components (sedimentation basins and digesters) are less resilient.

#### 5. *Mitigation for Statewide Water System: Aqueducts, Canals, Levees, Dams, and Reservoirs*

Major seismic hazard mitigation efforts include the East Side Reservoir Project in Riverside County, the Olivehain Dam in San Diego County, and the Calaveras Dam Replacement Project (see [Annex 2, Section 2.4.3](#) for more information). The East Side Reservoir Project includes canals, pipeworks, a new dam, and a reservoir intended to provide water to a large portion of the Los Angeles metropolitan region for up to six months should an earthquake take the California Aqueduct out of service. The Olivehain Dam and reservoir are intended to provide San Diego with water should there be interruptions of water from the Colorado River after earthquakes. For full discussion of dam failure hazards and current mitigation efforts, see [Chapter 7, Section 7.5, Dam Failure and Safety](#).

The San Francisco Bay-San Joaquin-Sacramento Delta region contains levees critical for delivering irrigation water to 3 million acres and drinking water to over 23 million people. A failure in one of the Delta levees in 1972 interrupted the state and federal water supply systems and required approximately 500,000 acre-feet of fresh water to restore export water to acceptable quality, according to Senate hearings on the 1972 levee failure at Andrus-Brannan Islands. Recent studies indicate that the levees in the Delta are susceptible to significant damage in a near-field seismic event. For full discussion on levees, see [Chapter 7, Section 7.4, Levee Failure, and Safety](#).

<sup>127</sup> FEMA P-751 and P-752 (2013).

### 6. *Mitigation for Solid Waste Disposal Systems (Municipal and Hazardous Waste Landfills)*

The 1994 Northridge Earthquake shook many landfills and caused sliding and damage, primarily in the cover systems. This information has since been used to improve the seismic design of landfills and landfill systems.<sup>128</sup> The risk of vulnerability associated with seismic activity at landfills is lessened through implementation of seismic design standards. These standards ensure that a structure is designed to withstand ground movement while taking into consideration the proximity and the geology between the location of the structure and faults.

The foundation or base of the landfill is constructed so it can provide support for the structures and withstand hydraulic pressure gradients to prevent failure due to settlement, compression, or uplift along with all effects of ground motions resulting from an earthquake. Also, based on the landfill classification and the proximity to known Holocene faults throughout California, the design would be able to withstand a range of earthquake magnitudes. Lastly, for any landfills seeking closure status, a slope stability analysis would be necessary to evaluate the integrity of the slopes to protect public health and safety and prevent damage to post-closure land uses, roads, structures, utilities, gas monitoring and control systems, and leachate collection and control systems to prevent public contact with leachate and to prevent exposure of waste.

### 7. *Mitigation for Transportation Systems*

Caltrans transportation system mitigation actions include the following:

- The Highway Bridge Program to replace or rehabilitate public highway bridges over waterways, other highways, or railroads when the state and the Federal Highway Administration determine that a bridge is significantly important and is unsafe because of structural deficiencies, physical deterioration, or functional obsolescence. Approximately \$240 million in federal funds are made available to local agencies annually under the Transportation Equity Act for the 21st Century (TEA21).
- The Culvert Inspection Program, intended to preserve and upgrade the state's investment in highway drainage infrastructure. The inspections identify drainage and structural deficiencies to be addressed by major maintenance and capital rehabilitation/replacement contracts.

#### **Progress Summary 6.K: Highway Bridge Retrofits**

**Progress as of 2018:** Since the 1989 Loma Prieta Earthquake, approximately \$14 billion in state highway earthquake retrofit improvement funds have been committed and largely completed. The following is a brief statewide synopsis of California state transportation system mitigation outcomes for highway bridge retrofits.

#### **State and Local Bridge Improvements**

There are over 12,800 state and 12,300 local bridges in California. Of the 2,194 state bridges previously determined to need seismic retrofitting (identified for retrofit in two phases), all but one have been retrofitted as of May 2018. The final project left to complete is the replacement of the Schuyler Heim Bridge in Long Beach. Anticipated completion date is late 2020 or 2021. As of December 2016, the current expenditure of bridge retrofit Phases 1 and 2 is \$2.583 billion. The final cost will total \$2.827 billion.

Highway bridges retrofitted as part of the state's \$12-billion highway bridge earthquake strengthening program have demonstrated resilience in large earthquakes. According to a study released by the California Seismic Safety Commission in 2016, the 2014 South Napa Earthquake demonstrated how recently retrofitted bridges performed as compared to those with no substructure retrofit.<sup>129</sup> Prior to 2014, all 412 state-owned highway bridges in Solano, Napa, and Sonoma Counties had been evaluated and 54 retrofitted. New and recently retrofitted state-owned bridges outlasted the Magnitude 6.0 earthquake without any serious damage. The Napa Slough Bridge did not have a sub-structure retrofit and experienced serious damage to its pile extensions.

<sup>128</sup> Bray, J. D., Augello, A. J., Leonards, G. A., Repetto, P. C., & Byrne, R. J. (1995). Seismic stability procedures for solid-waste landfills. *Journal of geotechnical engineering*, 121(2), 139-151.

<sup>129</sup> [http://peer.berkeley.edu/publications/peer\\_reports/reports\\_2016/CSSC1603-PEER201604\\_FINAL\\_7.20.16.pdf](http://peer.berkeley.edu/publications/peer_reports/reports_2016/CSSC1603-PEER201604_FINAL_7.20.16.pdf)

**Toll Bridge Improvements**

Senate Bills 60 and 226 established the Toll Bridge Program and provided initial retrofit funding. Assembly Bills 1171, 144 and 1175 established current funding for the nine bridges in the toll bridge System. Seismic retrofitting has been completed on all nine bridges in the toll bridge system as of December 2016 at a cost of \$9.435 billion.

**San Francisco-Oakland Bay Bridge**

Among the toll bridges recently retrofitted, the new separately funded \$6.416 billion Bay Bridge, straddling two major faults and connecting San Francisco and Oakland, is now the largest and most expensive single-tower, self-anchored suspension bridge in the world. While the project was initiated after the 1989 Loma Prieta Earthquake, the groundbreaking took place 13 years later in 2002, at twice the cost originally estimated. The first approved design met seismic safety objectives but was rejected by the public in 1997 because it did not do justice to the bridge's prominence symbolically, physically, or economically. The ensuing public process illustrates how competing values can affect mitigation efforts, including the risk inherent in delay.

The comprehensive retrofit of this bridge was completed in 2013 and the entire span of the San Francisco-Oakland Bay Bridge was reopened to traffic on September 2, 2013. The new bridge is designed to meet the most stringent earthquake standards and to act as a regional lifeline structure, opening quickly to traffic after the strongest ground motions that engineers expect in a 1,500-year period. This is in sharp contrast to the original East Span (Oakland-Yerba Buena Island), which was designed with truckloads and winds, rather than seismic safety, in mind. The new structure, including the bridge and its approaches, is 8.4 miles long. This length extends from the MacArthur Maze freeway interchange in Oakland to the end of the Fifth Street off-ramps in San Francisco. Both the East and West Spans of the bridge have undergone seismic retrofits. The bridge was recognized as the world's widest bridge as of December 2016, with a total deck width of 258.33 feet, and is the first in the Bay Area to feature pedestrian and bicycle paths.

The new East Span consists of a self-anchored suspension bridge with a single steel tower and a 1.2-mile-long elevated skyway viaduct that descends gradually toward the Oakland shoreline. This new span has been made seismically resilient with new technology and enhancements, some never before used in bridge building. Seismic innovations, such as fusible shear links in the tower, battered piles in the skyway's foundations, and hinge pipe beams in the road decks, have been designed to absorb the damage from an earthquake and to protect the structural elements of the bridge. The self-anchored suspension required 67,000 tons of steel for its superstructure and tower. These innovations will allow the bridge not only to withstand heavy seismic activity, but to last for its expected 150-year lifespan. As of December 2016, the East Span is world's longest self-anchored suspension bridge, totaling 2,047 feet. The West Span of the bridge between San Francisco and Yerba Buena Island underwent extensive seismic retrofitting yet retains its original appearance. On the west approach, a 1-mile stretch of Interstate 80 in San Francisco, six on- and off-ramps were demolished and rebuilt. The upper and lower decks were given independent columns and foundation support systems. On the West Span, a half million original rivets were replaced with nearly twice as many high-strength bolts. Seventeen million pounds of structural steel were added, and new bracing was installed under both decks. The "laced" diagonal crossbeams connecting the upper and lower road-decks were replaced with perforated steel.

Embedded throughout the bridge is monitoring equipment installed and maintained by the California Geological Survey that will collect information on earthquake shaking from nearby earthquakes. These devices, called accelerographs, will monitor and measure how the bridge responds to ground motion in an earthquake. There are 86 sensors in the self-anchored suspension, 80 in the West Span, 73 in the skyway, 28 in the Yerba Buena Island section, and 12 in the Oakland touchdown area. After an earthquake, the sensors will transmit the data to create a digital map showing the location and intensity of seismic activity and ground motion. Crews can use the maps to determine potential damage to infrastructure including road and water lines.

For more information regarding the Bay Bridge seismic retrofit, visit the project website:

<http://www.baybridgeinfo.org/>.

### 8. *Ports and Harbors*

The American Society of Civil Engineers has created Seismic Guidelines for Ports (ASCE 61-14). The guidelines provide generalized information for assessing seismic hazards for use in developing seismic hazard mitigation design criteria. The guidelines are based on observations of the performance of ports and harbors after earthquakes around the world. Several ports and harbors have also conducted seismic hazard mitigation projects. These guidelines will be superseded by ASCE 61-19, which is still under development, as of early 2018.

### 9. *Communication Systems*

The U.S. Geological Survey (USGS), the California Geologic Survey (CGS), and other partners developed the HayWired scenario as a tool to enable further actions that can change the outcome when the next major earthquake strikes. The HayWired scenario is the latest in a series of projects through the USGS Science Application for Risk Reduction (SAFRR) Program, which focuses on potential impacts when the Hayward Fault again ruptures through the east side of the San Francisco Bay region, as it last did in 1868. Cities in the East Bay along the Richmond, Oakland, and Fremont corridor would be hit hardest by earthquake ground shaking, surface fault rupture, aftershocks, and fault afterslip, but the impacts would reach throughout the bay region and far beyond. The HayWired scenario name reflects California's increased reliance on the Internet and telecommunications and also alludes to the interconnectedness of infrastructure, society, and California's economy.

By illuminating the likely impacts on the present-day built environment, well-constructed scenarios can and have spurred officials and citizens to take steps that change the outcomes the scenario describes, whether used to guide more realistic response and recovery exercises or to launch mitigation measures that will reduce future risk.

The first volume of the Haywired scenario report was published in 2017 and covers the physical aspects of what might happen—shaking, fault rupture, liquefaction, landslides, and aftershocks. Subsequent volumes will address the consequences and estimated losses.

To download the HayWired Earthquake Scenario – Earthquake Hazards report, visit:  
<https://pubs.er.usgs.gov/publication/sir20175013>.

## 6.1.5.4 PUBLIC OUTREACH AND EARTHQUAKE AWARENESS

### **Great California ShakeOut Earthquake Drill**

The Great California ShakeOut earthquake drill is an annual initiative where the public is encouraged to practice self-protective measures and to take other actions that promote earthquake resiliency.

ShakeOut registration not only encourages drill participation, but also promotes mitigation and preparedness. Moreover, it leverages the broad public visibility of the drill day to get people talking about preparedness and mitigation with people they care about. This promotion of “social milling” is based on social science indicating that people are most likely to change behavior around earthquake preparedness and mitigation if they talk about it with people they know, and when they see people like themselves taking action. The “hook” for ShakeOut is a “Drop, Cover, and Hold On” drill to encourage people to practice how to protect themselves during strong shaking. The ShakeOut initiative also provides information on “The Seven Steps to Earthquake Safety.”

### *ShakeOut as Part of Earthquake Education Stakeholder Networking*

ShakeOut would not be possible if “led” in a traditional way by a single organization. It is coordinated by a broad coalition of organizations across sectors. Government jurisdictions, agencies, organizations, schools, community groups, and individuals are all encouraged to register and “create their own drill” that meets their organization's goals. Outreach for ShakeOut depends on the Earthquake Country Alliance (ECA), a collaboration among three regional coalitions as well as statewide organizations, each attracting a broad base of stakeholders.

ECA broadens the definition of earthquake mitigation/education stakeholders. It is a statewide public-private partnership of people, organizations, and regional alliances that work together to improve preparedness, mitigation, and resiliency. ECA's goal is to create a culture of resiliency for all Californians; ECA therefore depends on leveraging efforts and sharing strengths. This network is an important platform to deliver preparedness and mitigation information to all sectors, but it is also an important method for coordinating and unifying messages across various regions and organizations that develop and deliver such messages.

ECA's regional partners include the Southern California Earthquake Alliance, the Bay Area Earthquake Alliance, and the Redwood Coast Tsunami Work Group. Strategic partner organizations include the California Governor's Office of Emergency Services (Cal OES), U.S. Geological Survey (USGS), California Earthquake Authority (CEA), Southern California Earthquake Center, California Geological Survey (CGS), Federal Emergency Management Agency (FEMA), American Red Cross (ARC), State Farm Insurance, and many others.

#### *Mitigation Outreach as Part of "Readiness"*

The Great ShakeOut is not advertised specifically as a mitigation event. "Mitigation" is a technical term used more by professionals; it does not typically resonate with the public in the same way as other emergency management terms like "preparedness" or "recovery." ShakeOut does carry mitigation as an important part of its comprehensive public message. Mitigation information is presented as part of every ShakeOut, with "Secure Your Stuff" (non-structural mitigation). The ShakeOut initiative and the underlying structure of ECA will continue to offer potential value for future mitigation efforts. They have educated millions of people about their proximity to earthquake hazards. The hope is that the increased consciousness of risk will translate into interest in mitigation as well as preparedness.

The Great California ShakeOut also has potential mitigation benefits as a result of the networks it has created. ShakeOut continues to seek partners with an interest in reducing disaster losses and building communities of concerned individuals. These individuals and communities can be called on in the future to review mitigation actions, suggest mitigation improvements, assist in collecting data, and implement mitigation measures,

As agencies prepare for each upcoming ShakeOut, participants are encouraged to include mitigation as part of their message. This can include providing additional mitigation information on the ShakeOut website. Central to the ECA's mission is a broad approach to public and community readiness and resilience. This broad approach is designed to integrate mitigation into a comprehensive public message that will "shift the culture of readiness in California."

ShakeOut emphasizes actions the public can take to increase their earthquake readiness and their ability to recover. On drill day, businesses, organizations, and municipalities are encouraged to participate in the drill with additional activities beyond the "Drop, Cover, and Hold On" drill, including "Hazard Hunts" for non-structural hazards. To further promote drill registration and participation, ShakeOut includes many pre-drill events across the state.

#### *ShakeOut Partners: CEA and Red Cross*

Since 2012, the CEA has sponsored the "Get Prepared, California!" Auction to raise funds for American Red Cross (ARC) disaster-preparedness and relief efforts in California. Total funds raised over this period exceed \$1,060,000.

The CEA continues to develop communications programming that seeks to make earthquake preparedness a part of California culture and give the state's residents the strength to rebuild after the next damaging earthquake.



warning called ShakeAlert. The ShakeAlert system is designed to identify and characterize an earthquake a few seconds after it begins and deliver a warning to people and critical infrastructure that could be affected.

Development of the ShakeAlert earthquake early warning system was recognized as a significant mitigation step, and in September 2013 Senate Bill (SB) 135 passed, requiring Cal OES core partners to develop a comprehensive statewide earthquake early warning system through public-private partnerships. California Government Code Section 8587.11 states that the California Integrated Seismic Network (CISN) shall be responsible for the generation of an earthquake early warning alert. The strong motion instrumentation program is converting a number of its field instruments to incorporate the early warning system.

The 2016-2017 budget passed by the Legislature and signed by the Governor included \$10 million in funding to support the installation of 183 new seismic sensors and four permanent positions to perform research on necessary technology and other technical aspects that will integrate public and private infrastructure, provide public education, and conduct education and training. In September 2016, SB 438 was signed into law to further advance the development of the early warning system by establishing a governance structure to coordinate and direct activities related to the establishment of a statewide system. The implementation of the California Earthquake Early Warning Program (CEEWP) establishes Cal OES as the lead for implementing the statewide system and ensuring its continued long-term success.

### *Mitigation Benefits*

Advances in scientific understanding of earthquakes and technological developments have resulted in the capacity to rapidly analyze earthquakes and provide products that are vital to emergency management and public safety. One such advancement is the capability to provide early warning of an earthquake a few to several seconds prior to the actual arrival of destructive ground motions from a large and damaging seismic event.

The seconds or minutes of advance warning can provide people with an opportunity to take actions like "Drop, Cover, and Hold On" to protect life and property from destructive shaking. An earthquake early warning system can give enough time to slow and stop trains and taxiing planes, to prevent cars from entering bridges and tunnels, to move away from dangerous machines or chemicals in work environments and to take cover under a desk, or to automatically shut down and isolate industrial systems.

Taking such actions before shaking starts can reduce damage and casualties during an earthquake. It can also prevent cascading failures in the aftermath of an event. For example, isolating utilities before shaking starts can reduce the number of fire initiations. This effort aligns with state hazard mitigation goals and objectives to protect life loss and property.

Countries around the world including Mexico, Japan, Turkey, Romania, China, Italy, and Taiwan have implemented earthquake early warning systems. During the 2011 Magnitude 9.0 earthquake in Japan, the televised warning gave viewers more than a minute of notice before the strongest shaking arrived in Tokyo. In September 2017, Mexico experienced a Magnitude 7.1 earthquake that killed over 230 people. Mexico City, which is located about 75 miles away from the epicenter, had more than 20 seconds of siren warning to prepare for the impending shaking, enough time for people to flee vulnerable buildings and take protective measures.

**Case Study: 2014 South Napa Earthquake – A Milestone for California’s Earthquake Early Warning System**

In August 2012, Bay Area Rapid Transit (BART) became the first transit agency in the United States to adopt an earthquake early warning system. If the system senses an earthquake above Magnitude 4.0 for local earthquakes and Magnitude 5.0 for farther away, the BART central computers that manage train movement will automatically slow trains down to 26 miles per hour. The system can provide up to 50 seconds of warning if the shaking is far away. The automated earthquake early warning signals to trains have the advantage of not requiring human reaction time, increasing the potential of saving lives during a major earthquake.

On August 24, 2014, at roughly 3:20 a.m. local time, an earthquake occurred in and around the City of Napa, California. The epicenter was located south of Napa, approximately 3.7 miles northwest of American Canyon near the West Napa Fault. The earthquake, measuring Magnitude 6.0, was the largest earthquake in the Bay Area since the 1989 Loma Prieta Earthquake. The South Napa Earthquake resulted in 1 death and approximately 200 people injured. Shortly after, Governor Jerry Brown declared a state of emergency due to the damage and the possibility of damage resulting from aftershocks. It is estimated that the earthquake caused over \$400 million in damage.

The 2014 South Napa Earthquake served as important milestone for California’s earthquake early warning system for two reasons: It was the first true test of the system, and the system successfully provided warning to nearby communities. On-site warning systems installed at five fire stations in Vallejo in 2002 successfully commanded the bay doors to open at these fire stations before the earthquake arrived. Similarly, had BART trains been operating, the system would have received a six-second warning, enough time to reduce the speed of trains by 12 miles per hour (or 2 miles per second), significantly reducing the likelihood of derailment.

**Program Technology**

The objective of earthquake early warning systems is to rapidly detect the occurrence of an earthquake, estimate the level of ground shaking to be expected, issue a warning before significant ground shaking begins, and estimate the location and the magnitude of the earthquake.

When an earthquake occurs, it produces different types of shock waves, which travel at different speeds. The fastest and weakest of these waves are called P-waves. Technology exists that can detect the energy from P-waves to estimate the location and the magnitude of the earthquake. This method can provide warning before the more destructive S-wave arrives. The S-wave is typically responsible for most of the strong shaking that usually creates the most damage during earthquakes.

The amount of warning time at a particular location depends on the distance from the earthquake epicenter. Locations very close to the earthquake epicenter will receive relatively little or no warning whereas locations far removed from the earthquake epicenter will have more warning time but may not experience damaging shaking.

Studies on earthquake early warning methods in California concluded that the warning time would range from a few seconds to a few tens of seconds, depending on the distance from the earthquake epicenter. However, very large earthquakes emanating from the San Andreas Fault could produce significantly more warning time because the affected area would be much larger.

The time required to detect and issue a warning for an earthquake is dependent on several factors:

1. *Distance between the earthquake source and the closest seismic network seismometer (station).* It takes a finite amount of time (about one second) for seismic waves to travel from the source (i.e., the location where the earthquake started) to the seismic station. The first waves to arrive at a station are the less damaging P-waves that travel at on average of 3 to 4 miles per second, and the more damaging S waves travel at approximately 1 to 2 miles per second. The closer a station is to the source, the more rapidly the ground motion measurements from earthquake are identified, and the more rapidly the information about the earthquake is sent to the data processing center.

2. *Transfer of information to the regional networks.* Data from multiple stations must be collected and analyzed by the regional seismic networks to issue a warning. Ground motion information must be transferred from each station to the processing center. The existing network uses a variety of methods including radio links, phone lines, public/private internet, and satellite links to send data back to the processing center. Delays from packaging and transmitting the data from the station to the processing center and the processing center to the recipient must be reduced to provide useful warning times.
3. *Detection and characterization of an earthquake.* Real-time ground motion information received from the stations is used to detect an earthquake and rapidly determine the location and magnitude of the event. Multiple algorithms (a mathematical procedure used to compute a desired result) are used to estimate the earthquake information as rapidly as possible.

Regardless of the warning time, earthquake early warning systems can provide adequate time to slow down and stop trains, stop cars from entering tunnels, automatically shut down dangerous machinery, and countless other benefits. Taking such actions before an earthquake arrives can reduce damage and casualties during and after an earthquake.

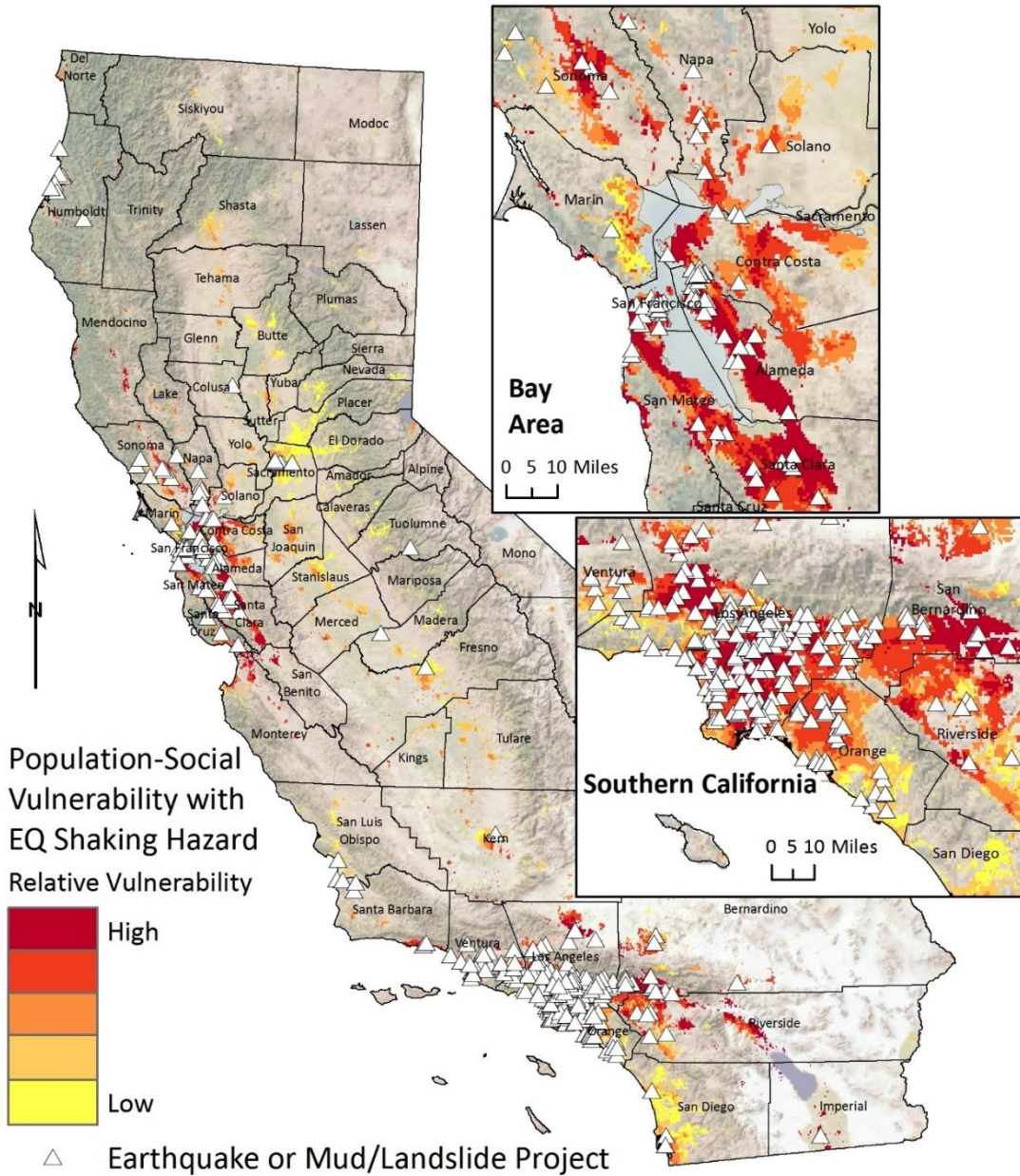
For more information, visit the ShakeAlert program website: <http://www.shakealert.org/>.

#### **6.1.5.5 FEMA-FUNDED SEISMIC HAZARD MITIGATION PROJECTS**

Map 6.X shows the distribution of earthquake-related FEMA Hazard Mitigation Assistance grant funded projects in relation to vulnerable populations (based on the index described in [Appendix N](#)) in high earthquake hazard areas. More mitigation projects are in Southern California and the San Francisco Bay Area than in other parts of the state, coinciding with areas of higher population and social vulnerability to earthquake hazards.

Map 6.X: FEMA Funded Earthquake Mitigation Projects and Population Vulnerability, 1994-2017

FEMA Funded EQ Mitigation Grants 1994 - 2017  
with Pop/Soc Vulnerability to Earthquakes



Cal Poly - San Luis Obispo  
City and Regional Planning  
June 2018

Source: Cal OES

0 25 50 100 Miles

Created by: C. Schuldt (6.X-FEMA Funded EQ Projects and Pop-SocVuln.mxd)

### 6.1.6 ADDITIONAL EARTHQUAKE HAZARD MITIGATION OPPORTUNITIES

In partnership with the Pacific Earthquake Engineering Research Center (PEER), the California Seismic Safety Commission (CSSC) published “The MW 6.0 Earthquake in South Napa Earthquake of August 24, 2014: A Wake-Up Call for Renewed Investment in Seismic Resilience across California” in June 2016. The report discusses 20 findings and priority recommendations (summarized in Tables 6.I and 6.J) into the categories of Geosciences, Infrastructure, Buildings, People and Business, and Government and Institutions.

**Table 6.I: 2016 Napa Earthquake Report Findings**

No.	Finding
<b>1. Geosciences</b>	
1.1	The South Napa Earthquake is the first earthquake to produce significant surface rupture in Northern California since 1906, and the first surface fault rupture to impact housing in the 40 years of the Alquist-Priolo Earthquake Fault Zoning Act.
1.2	Afterslip on the West Napa Fault following the 2014 earthquake produced further damage and necessitated a regional-scale geologic investigation, on-going monitoring, and technical guidance for federal, state and local government, utilities, and property owners.
1.3	The South Napa Earthquake identified some critical gaps in mapping coverage and guidance that affected the abilities of city, county, and state agencies to identify and map seismic hazard zones and mitigate seismic hazards to protect public health and safety in accordance with the provisions of the Seismic Hazard Mapping Act of 1990.
1.4	Investments in strong-motion instrumentation and earthquake alerting systems, applications of advance remote sensing techniques, and activation of the California Earthquake Clearinghouse all were demonstrably valuable in assisting damage assessment and emergency response, even in a moderate earthquake.
<b>2. Infrastructure</b>	
2.1	The 2014 South Napa Earthquake demonstrated the long-term benefits of the state’s \$12 billion highway bridge earthquake strengthening program, which has screened and retrofitted (as needed) more than 2,200 structures statewide to prevent collapse during future earthquakes.
2.2	The South Napa Earthquake highlighted the vulnerability of natural gas transmission and distributions systems to earthquake-related ground failure.
2.3	The South Napa Earthquake highlighted the vulnerability of water and wastewater systems to earthquake-related ground failure, the additional fire hazards that earthquake-related water-system failures can pose, and the fiscal challenges that public agencies face in improving the seismic resiliency of these systems, both pre- and post-earthquake.
<b>3. Buildings</b>	
3.1	The South Napa Earthquake helped to identify important gaps in building safety evaluations and procedures to barricade unsafe areas that should be addressed statewide before the next major earthquakes strikes.
3.2	The City of Napa’s program to seismically retrofit unreinforced masonry buildings was successful in reducing damage and the risk to life safety posed by these buildings.
3.3	While modern buildings generally met or exceeded code performance standards in the Magnitude 6.0 earthquake, damage to non-structural components was the greatest contributor to property losses.
3.4	There was generally good performance across a range of wood-frame residential construction vintages and styles. The vast majority of damage was caused by two well-known seismic deficiencies: unbraced chimneys and cripple walls foundations.
3.5	The significant damage to manufactured housing in the 2014 South Napa Earthquake was almost exclusively associated with support systems rather than the homes themselves.
<b>4. People and Business</b>	
4.1	Deaths and injuries sustained in the South Napa Earthquake point to continuing gaps in public awareness and education on earthquake safety and preparedness.

No.	Finding
4.2	The 2014 South Napa Earthquake highlighted significant gaps in earthquake insurance coverage for both homeowners and businesses, and the need to improve both the affordability and terms of insurance coverage and plan for housing and business recovery funding needs ahead of a major urban earthquake in the state.
4.3	The delay in authorization of the federal Individual Assistance program hindered community recovery.
4.4	Insights from the 2014 South Napa Earthquake provide an opportunity to consider how state emergency proclamation provisions can accelerate and improve post-earthquake recovery for residents and businesses.
<b>5. Government and Institutions</b>	
5.1	The state's Standardized Emergency Management System was effective in mobilizing a multi-jurisdictional, multi-level emergency response following the South Napa Earthquake but some significant areas for improvement and training, particularly with smaller jurisdictions, have been identified.
5.2	The 2014 earthquake identified problems with the damage assessment and declaration processes and financing of local government post-disaster assistance that need to be addressed ahead of the next major urban earthquake in the state.
5.3	The 2014 earthquake highlighted significant gaps in contingency planning at many key government and critical facility operations.
5.4	More pre-disaster planning and training for post-disaster recovery is needed at both the state and local levels.

**Table 6.J: Priority Recommendations of the 2016 Napa Earthquake Report**

No.	Recommendation
<b>1. Geosciences</b>	
1.1	Identify the locations of complex and integrated fault zones in the state, like the West Napa fault zone, and prioritize these for evaluation and mapping and potential designation as Alquist-Priolo Earthquake Fault Zones.
1.2	Evaluate the aggregate effects of current amendments and exemptions under the Alquist-Priolo Earthquake Fault Zone Act and accompanying regulations, and study ways to better regulate and fund geologic investigations and structural mitigation in Alquist-Priolo Earthquake Fault Zones.
<b>2. Infrastructure</b>	
2.1	Ensure that all state-required gas safety plans address the mitigation of system risks to seismic hazards.
2.2	Convene a state task force that includes local water and wastewater providers as well as fire departments across the state to identify vulnerabilities, mitigation options, and financial mechanisms to enhance the seismic resilience of local water and wastewater systems, particularly in areas vulnerable to widespread ground failure and that lack alternative water supplies for firefighting.
<b>3. Buildings</b>	
3.1	Work with the Federal Emergency Management Agency, the California Building Officials, and other professional engineering and architectural organizations to: ensure that curricula for training and certification of safety assessors are effective and more widely implemented, particularly for local government personnel; improve protocols for deploying and compensating safety assessors; expand the use of Building Occupancy Resumption Programs; and grant safety assessment authority to the Division of the State Architect for public Kindergarten-12 <sup>th</sup> Grade (K-12) schools and state-owned buildings.
3.2	Work with the California Building Officials and professional engineering and architectural organizations, including the American Institute of Architects California Chapter and Structural Engineers Association of California, to develop guidance for local jurisdictions on effective coordination and management of post-earthquake safety assessment processes.
3.3	Develop guidance and training for local fire departments and building owners and operators on alternative procedures to safely turn off damaged sprinkler systems following earthquakes.

No.	Recommendation
3.4	Evaluate and enhance, as needed, training and inspection materials for school districts and staff to seismically secure non-structural systems, equipment, contents, and furnishings in public and private schools.
<b>4. People and Business</b>	
4.1	Establish a state task force to consider the risks posed to the state by the large proportion of uninsured residents and businesses in high-seismic hazard areas, and identify options for improving the take-up, affordability, and terms of earthquake insurance coverage for California residents and businesses, as well as alternative earthquake recovery funding sources for both residents and businesses.
4.2	Evaluate and enhance, as needed, penalties and other consumer protections against post-disaster scamming by contractors and cost inflation.
<b>5. Government and Institutions</b>	
5.1	Strengthen seismic performance standards and contingency planning for all state and local correctional facilities.
5.2	Review and revise, as needed, state regulations guiding the transfer and housing of inmates in county jails during times of emergency.

---

## 6.2 LANDSLIDE AND OTHER EARTH MOVEMENT HAZARDS, VULNERABILITY, AND RISK ASSESSMENT

### 6.2.1 IDENTIFYING LANDSLIDE HAZARDS

Like its earthquake-generating faults, California's mountainous terrain is also a consequence of dynamic geologic processes in operation as the Pacific Plate grinds past the North American Plate. More than one-third of California is mountainous terrain that generally trends parallel to the coast, forming a barrier that captures moisture from offshore storms originating in the Gulf of Alaska and Mexico. Steep topography, weak rocks, heavy winter rains, and occasional earthquakes all lead to slope failures more frequently than would otherwise occur under gravity alone.

A landslide is the breaking away and gravity-driven downward movement of hill slope materials, which can travel at speeds ranging from fractions of an inch per year to tens of miles per hour depending on the slope steepness and water content of the rock/soil mass. Landslides range from the size of an automobile to a mile or more in length and width and, due to their sheer weight and speed, can cause serious damage and loss of life. Their secondary effects can be far-reaching; for example, catastrophic flooding can result from the sudden release of river water impounded by landslide debris or slope failure of an earthen dam.

Although the area affected by a single landslide is less than that of earthquakes, landslides are pervasive in California's mountainous terrain and occur far more often, resulting in average annual landslide losses estimated at about \$200 million.<sup>131</sup> Because landslides occur as isolated events in both time and location, and there is presently no systematic means in place for documenting their losses, landslide hazard is often underestimated or goes unrecognized in the policy arena, even though landslides continue to cause millions of dollars in cumulative damage to California's homes, businesses, and infrastructure.

#### Deep-Seated Landslides

Deep-seated landslides (greater than 10 to 15 feet deep) tend to be triggered by deep infiltration of rainfall over a period of weeks to months. Some deep-seated landslides move very slowly while others can move quickly with little notice. These types of landslides generally cause extensive property damage, but rarely result in loss of life.

#### Debris Flows

When slope material becomes saturated with water, a debris flow may develop. From a geologic perspective, there are generally two types of debris flows.

##### Debris Flows Related to Shallow Landslides

The first type of debris flow occurs on hillslope due to soil failure in which soil liquefies and runs downhill. This type of debris flow generally results from a shallow landslide (less than 10 to 15 feet deep) and has a discrete initiation zone depositional area. Shallow landslides tend to occur in winter but are most likely after prolonged periods of heavy rainfall when soil materials are saturated. Debris flows are typically more dangerous because they are fast moving, causing both property damage and loss of life.

##### Post-Wildfire Debris Flows

The second type of debris flow is a result of post-fire conditions, where burned soil surfaces enhance rainfall runoff that concentrates in a channel and picks up debris as it moves. The post-fire debris flow has a less discrete initiation zone but is similar to a debris flow derived from hillslopes, in that it may result in inundation and a detrimental impact on lives and property within its zone of runout and deposition, and it can result in flooding downstream.

---

<sup>131</sup> Based on 2018 cost adjusted data from Brabb, E.E., 1989, Landslides: Extent and economic significance in the United States in Proceedings 28th International Geological Congress Symposium on Landslides, Washington D.C., 17 July 1989: A.A. Balkema Publishers, Rotterdam, p 25-50.

An example of a catastrophic post-fire debris flow is the event that occurred in Santa Barbara County on January 9, 2018, when, after the Thomas Fire, numerous canyons deposited debris flows onto urbanized alluvial fans in Montecito and Carpinteria.

### Alluvial Fans

Alluvial fans are geologic features built by successive runoff spreading out on the broad fan-like surface as debris-laden floods or debris flows are deposited. The processes that formed these fan landforms become increasingly active with the occurrence of earthquakes, wildfires, and strong winter storms.

As residential and business land uses have expanded onto mountain-front alluvial fan areas, more lives and property are at risk from occurrence of debris-laden floods and debris flows in alluvial fan areas.

## 6.2.2 PROFILING LANDSLIDE HAZARDS

Landslides are classified into many different types based on form and type of movement. They range from slow-moving rotational slumps and earth flows, which can slowly distress structures but are less threatening to personal safety, to fast-moving rock avalanches and debris flows that are a serious threat to structures and have been responsible for most fatalities during landslide events. Many large landslides are complex, being a combination of more than one landslide type. This is well illustrated by the famous La Conchita landslide that lies along the coastal bluffs in Ventura County. Historically active since the turn of the 19th century, it was reactivated as a slow-moving rotation slide during the 1995 winter rains that destroyed six homes in the subdivision below. The slow movement allowed homeowners to evacuate safely, resulting in no injuries during the event. A portion of the same landslide moved again during the 2005 heavy winter rains as a fast-moving debris flow, which destroyed 30 more homes but also caused 10 fatalities as the occupants had no time to escape.

### Areas of Landslide Risk

Landslide hazards are present in many regions of California. Landslide probability is notably high in the coastal regions of California, which are home to much of the state's population, industry, and infrastructure. Particularly hazardous terrain lies where weak rock layers are inclined in the same direction as the mountain slope, a condition found in many areas of California. The Franciscan Formation, which makes up much of the Northern California Coast Ranges, contains weak rock that is both easily eroded and landslide-prone. Through the decades, development has been continuing to spread into mountainous terrain where hazard exposure is high. Most reported landslide losses occur in these regions, as illustrated in the cumulative landslide occurrences resulting from the 1995 El Nino winter storms, shown in Map 6.Y.

#### Debris Flows and Alluvial Fans

Alluvial fans are a type of landform where debris flows tend to deposit. They range from small features on the order of an acre, to massive landforms that are visible from space. According to U.S. Geological Survey (USGS), about 10 inches of seasonal rain are necessary for ground saturation in Southern California. Once the ground is saturated, as little as 0.2 inch of rain per hour has the potential to trigger a debris flow that could deposit on an alluvial fan.

With post-fire debris flows, wildfire can significantly alter the hydrologic response of a watershed to the extent that even moderate rainstorms can produce dangerous flash floods and debris flows. Seasonal rain accumulations on burn areas have little influence on debris flow generation. However, short-duration, intense rainfall, generally greater than 0.5 inch per hour, has the potential to trigger post-fire debris flows. As the rainfall intensity increases above this value, the magnitude and impacts of the debris flows also increase. For example, the January 9, 2018 storm in Santa Barbara County triggered debris flows when rainfall intensities reached 6.48 inches per hour. This storm event initiated several debris flows within the Santa Ynez Mountains that inundated urbanized alluvial fan areas within Montecito and Carpinteria in Santa Barbara County, causing 21 fatalities and 28 injuries, destroying 127 homes and 6 commercial buildings, and damaging 307 homes and 17 commercial buildings.

**A Santa Clara County Debris Flow Triggered by Winter Storms Following the Loma Fire, 2017**

Source: Brian Swanson, California Geologic Survey

Hazard mitigation planning through hazard identification and mapping has not been completed with respect to debris flows hazards on alluvial fans. However, general alluvial fan awareness mapping was completed by the California Geological Survey (CGS), working with the California Department of Water Resources (DWR) Alluvial Fan Floodplain Evaluation and Delineation (AFFED) project, has developed geologic maps of Quaternary surficial deposits for nearly 35,000 square miles of Southern California. These maps provide geologic information on the general distribution of alluvial fans, as well as differentiation of geologic deposits that may represent the location of potential debris-laden floods and debris flows. As part of the AFFED project, these maps are intended to provide local agencies making land use decisions with the necessary tools to understand the characteristics and potential hazards.

**Debris flows in the Santa Rosa Mountains in San Diego County Spread Out on an Alluvial Fan**

Photo by Jeremy Lancaster, California Geological Survey

It has been recognized that debris-laden floods and debris flows on alluvial fan floodplains often originate from watersheds that burned during the previous fire season.<sup>132</sup> The concern for debris flows following wildfires is particularly acute in the Los Angeles Basin where urban areas encroach upon alluvial fans. Research by the US Geological Survey (USGS) in the western United States has refined the understanding of debris flows generated from recently burned watersheds.<sup>133</sup> Post-fire debris flow hazards assessments prepared by the USGS can be found at the following website: [https://landslides.usgs.gov/hazards/postfire\\_debrisflow/](https://landslides.usgs.gov/hazards/postfire_debrisflow/).

### Winter Storms and Landslide Events

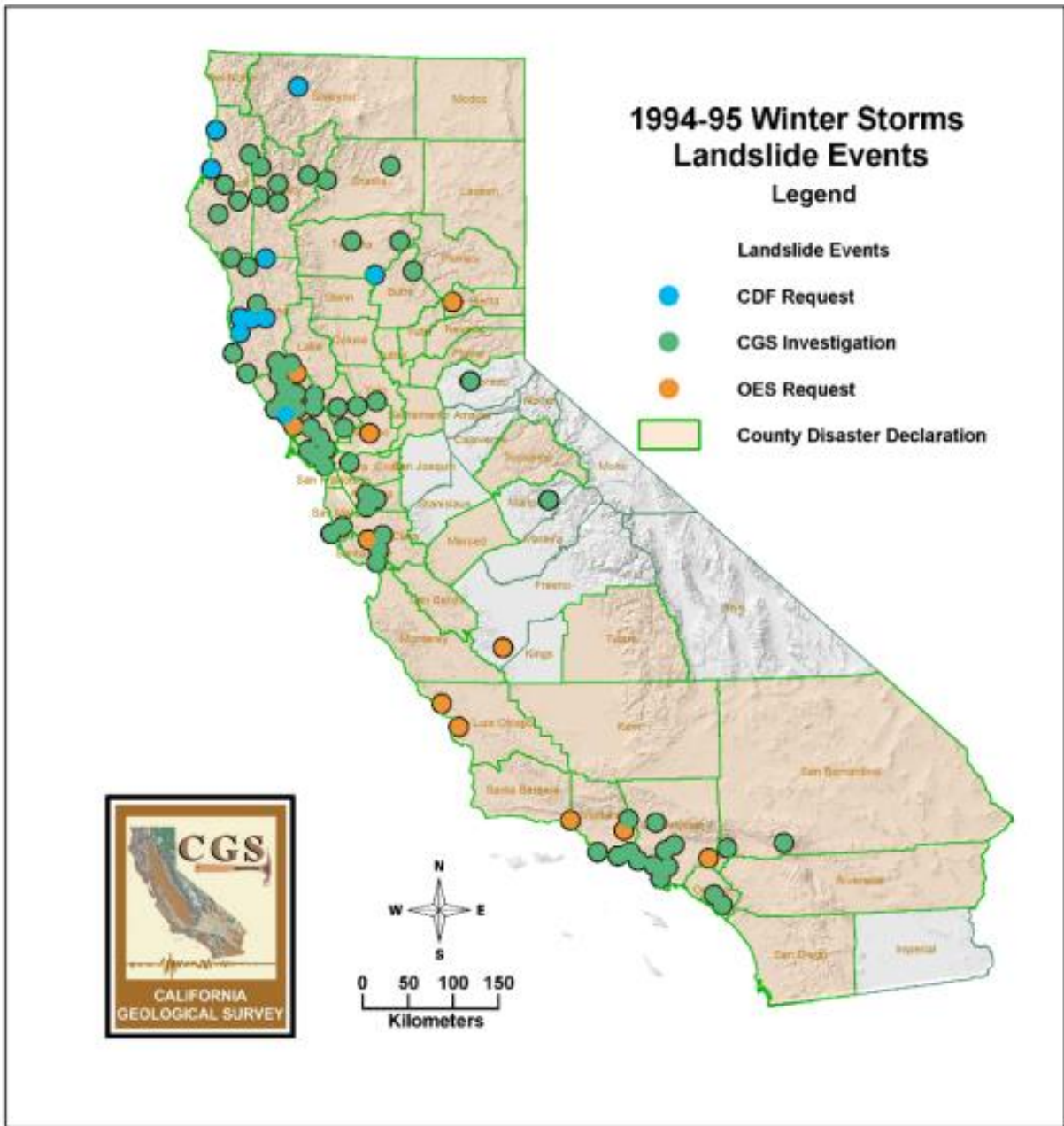
Map 6.Y shows the statewide distribution of landslide damage reports investigated by the California Geological Survey (CGS) during the 1995 El Niño winter storms. Orange-shaded counties are those declared federal disaster areas during the 1994-1995 winter season. While subsequent years have generated various landslide events in Northern and Southern California, there has not been a statewide landslide response since this map was prepared in 1995. However, landslides triggered during the February 2017 severe winter storms caused damage across a large portion of the state, with a major disaster declaration issued for 44 California counties and one tribe.

It should be noted that while Map 6.Y is over 20 years old, it is included in this document because it still demonstrates the relationship between extreme winter storm events and the potential for landslides to occur. As noted above, since there has not been a statewide landslide response since 1995, there is not a more recent version of Map 6.Y.

<sup>132</sup> Eaton, 1935

<sup>133</sup> USGS, 2005

Map 6.Y: 1994-1995 Winter Storm Landslide Events



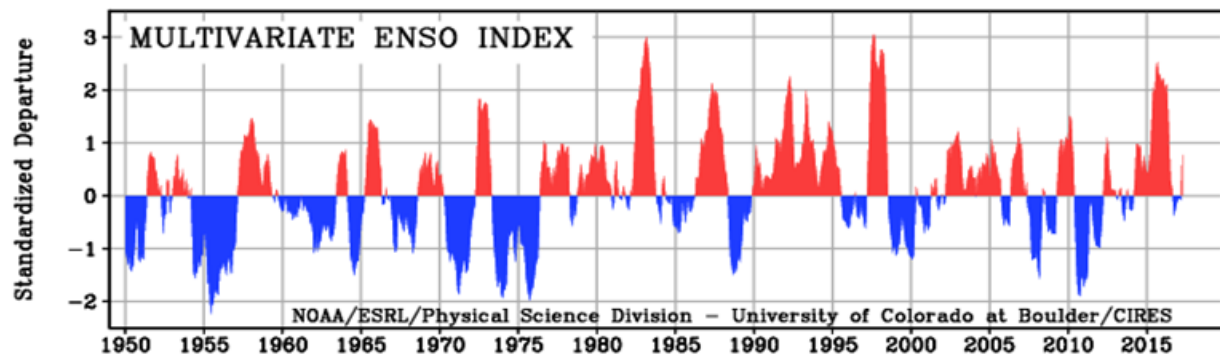
Other El Nino or high rainfall winter seasons that have strong atmospheric river storm events reveal similar patterns of landslide occurrences across the state. Even though Map 6.Y shows only one season, it illustrates a pattern of landslide propensity in certain regions when soils become saturated.

This statewide pattern of landslide occurrences repeats itself during heavy winter seasons, which may coincide with El Nino Southern Oscillation in the Pacific Ocean. Every few years, warm equatorial waters are driven to the eastern Pacific, bringing moisture-laden air that results in more frequent and severe winter storms in California. While El Nino is a condition that can result in high total rainfalls, there are other conditions that may result in record levels of rainfall, even in a non-El Nino year. The February 2017 severe storms were an example of an instance where

record-breaking rainfall occurred in a non-El Niño condition year with wet conditions instead resulting from many atmospheric rivers making landfall in the midst of a Madden Julian Oscillation event.<sup>134</sup>

During heavy rainfall conditions, the added weight of rain-saturated hill slopes and the weakening of slopes caused by the pressure the groundwater exerts on porous hillside materials are triggering agents of slope failure. Improved forecasting of El Niño events or other potentially high rainfall years now provides advanced warning which allows for better preparation and response to potential slope failures and flood events.

**Chart 6.A: Multivariate El Niño Southern Oscillation Index**



Source: NOAA, Earth System Research Laboratory, <https://www.esrl.noaa.gov/psd/enso/mei/> (retrieved June 1, 2017)

Chart 6.A shows a history of El Niño occurrences. El Niño Southern Oscillation (ENSO) is the most important coupled ocean-atmosphere phenomenon to cause global climate variability on interannual time scales. The red region corresponds to warmer sea surface temperatures, which bring unusually moist air into the north Pacific, producing wetter winters and more intense landslide and debris flow activity in California.

<sup>134</sup> NOAA Climate Prediction Center, <http://www.cpc.noaa.gov/>, <https://www.climate.gov/>

Figure 6.B: Landfalling Atmospheric Rivers from October 2016 to March 2017

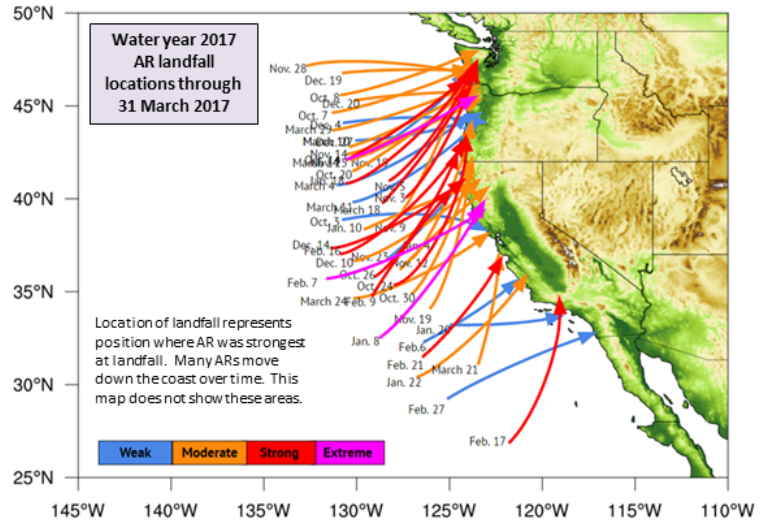
**Distribution of Landfalling Atmospheric Rivers on the U.S. West Coast**  
(From 1 Oct 2016 to 31 March 2017)

AR Strength	AR Count*
Weak	11
Moderate	20
Strong	12
Extreme	3

**Ralph/CW3E AR Strength Scale**

Weak	IVT=250–500 kg m <sup>-1</sup> s <sup>-1</sup>
Moderate	IVT=500–750 kg m <sup>-1</sup> s <sup>-1</sup>
Strong	IVT=750–1000 kg m <sup>-1</sup> s <sup>-1</sup>
Extreme	IVT>1000 kg m <sup>-1</sup> s <sup>-1</sup>

- 45 Atmospheric Rivers have made landfall on the West Coast thus far during the 2017 water year (1 Oct. – 31 March 2017)
- This is much greater than normal
- 1/3 of the landfalling ARs have been “strong” or “extreme”



\*Radiosondes at Bodega Bay, CA indicated the 10–11 Jan AR was strong (noted as moderate based on GFS analysis data) and 7–8 Feb AR was extreme (noted as strong)

Center for Western Weather and Water Extremes  
SCRIPPS INSTITUTION OF OCEANOGRAPHY AT UC SAN DIEGO

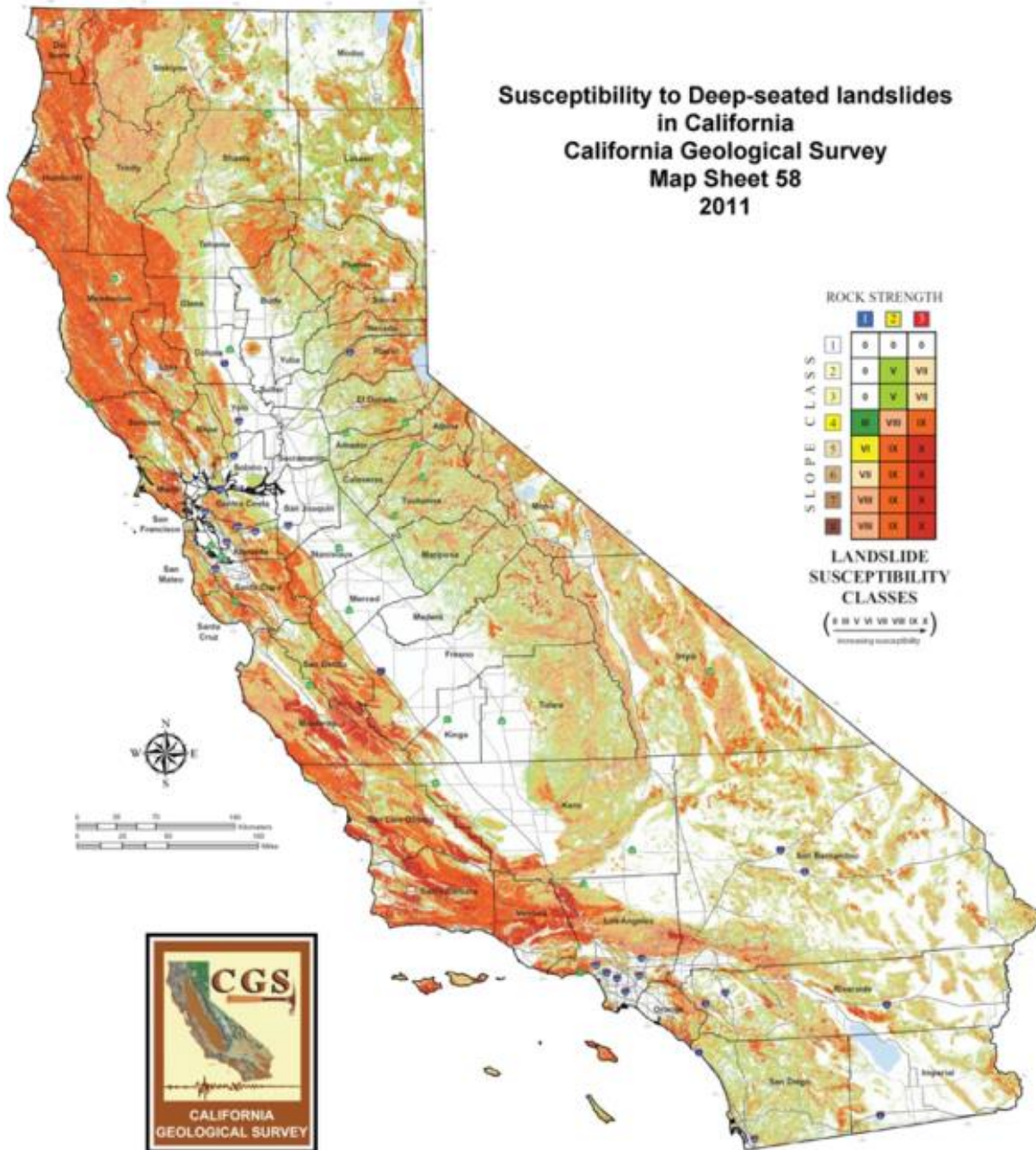
By F.M. Ralph, B. Kawzenuk, C. Hecht, J. Kalansky

*Experimental*

Source: <http://cw3e.ucsd.edu/how-many-atmospheric-rivers-have-hit-the-u-s-west-coast-during-the-remarkably-wet-water-year-2017/>

Figure 6.B summarizes the incidents of atmospheric rivers that made landfall along the west coast of the U.S from late 2016 through early 2017. While many of the strong and extreme atmospheric rivers landed north of California, several landings occurred within the state, bringing an increased risk of landslide occurrence.

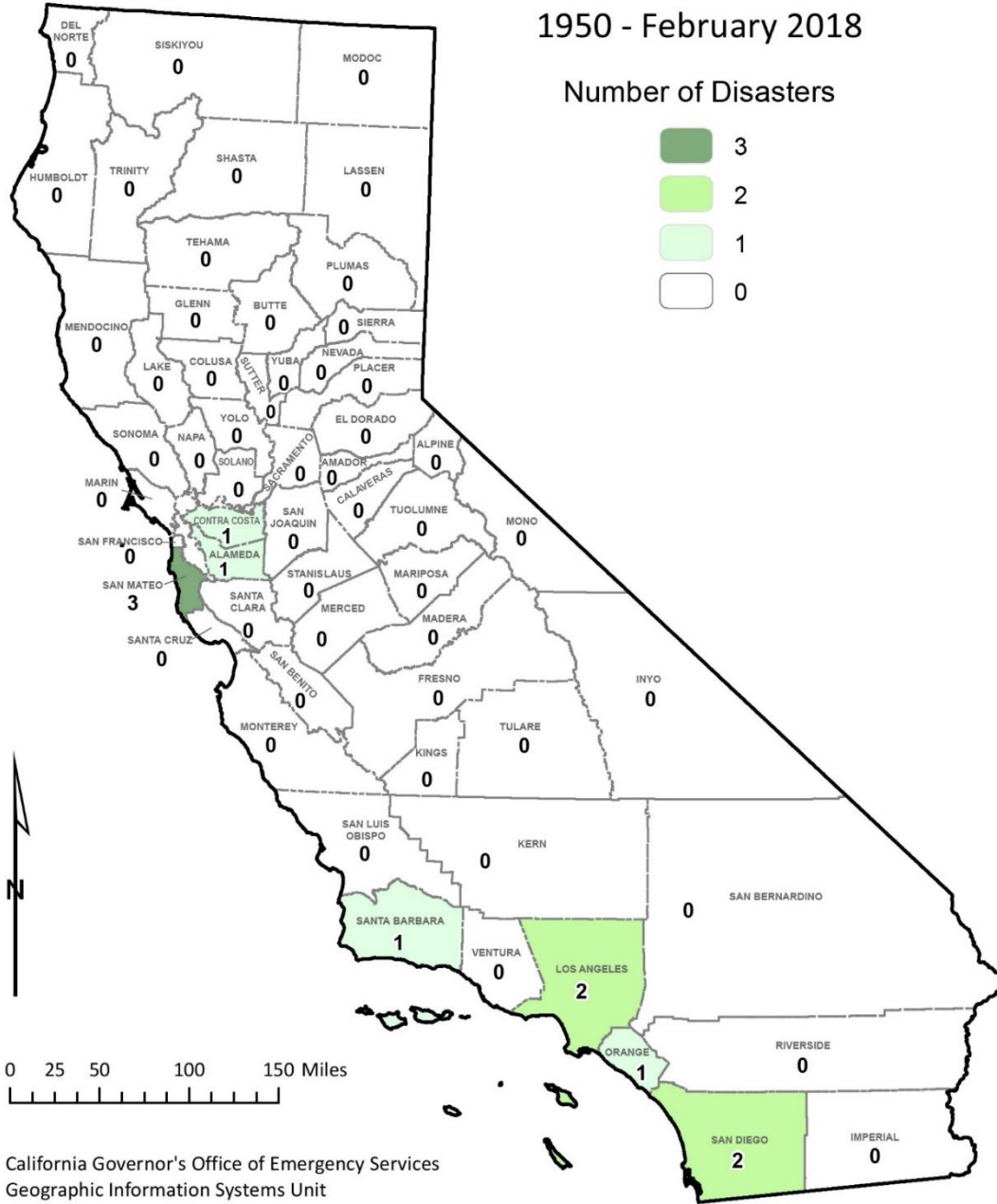
Map 6.Z: Relative Susceptibility to Deep-Seated Landslides in California



General landslide susceptibility in California can be estimated from the distribution of weak rocks and steep slopes as shown in Map 6.Z. High and moderate landslide susceptibility, combined with high rainfall or high earthquake potential, leads to high landslide hazard in coastal California.

Map 6.AA: State and Federal Declared Landslide Disasters, 1950-February 2018

## State and Federal Declared Landslide Disasters 1950 - February 2018



California Governor's Office of Emergency Services  
Geographic Information Systems Unit  
March 2018

Source: Cal OES

Created by:  
Cal OES GIS  
SHMP ArcPro Project

Map 6.AA shows state and federally declared landslide disasters by county from 1950 to February 2018. Note that despite frequent local occurrence of landslides, these events are rarely large enough to qualify for a disaster declaration. Additionally, large landslides and debris flows are frequently included under other disaster categories.

## Earthquakes and Landslides

Although less frequent, the most devastating landslides worldwide have been triggered by earthquakes. Strong ground shaking can create the additional forces necessary to weaken slopes and cause those already distressed by gravity to fail. The greatest landslide disaster in history occurred in 1920 in central China, where a Magnitude 8.5 earthquake caused weak, wind-deposit slopes to collapse into a densely populated valley, killing an estimated 180,000 people.

Earthquake shaking can also rapidly weaken loose water-saturated sediments via liquefaction, which can greatly increase ground deformation and sliding, even on gentle slopes. This happened during the 1971 San Fernando Earthquake, when the soil beneath two earth-fill dams partially liquefied and shifted, causing partial collapse of both facilities. Those events resulted in over a half-billion dollars in damage and the temporary evacuation of 80,000 people below the dam.

Besides blocking the flow of streams and causing the potential for catastrophic flooding by sudden release of impounded waters, landslides can collapse into water bodies, causing very large, destructive tsunamis. In 1958, a Magnitude 8 earthquake collapsed a hillside into Lituya Bay, Alaska, causing a water splash wave that reached 1,720 feet up the mountain slope, stripping all vegetation. A massive landslide into the Vaoint Reservoir in Italy in 1963 caused a tremendous water splash wave that swept 800 feet over the top of the dam, causing a major flood that killed an estimated 2,600 people below. Grading during construction of reservoirs and alteration of the groundwater regime due to the impounded water can weaken the adjacent hillsides, which must be taken into consideration during design and construction.

## Climate Change and Landslides

Landslides can result from intense rainfall and runoff events. Projected climate change-associated variance in rainfall events may result in more high-intensity events, which may increase landslide frequency (i.e., due to wetter wet periods and drier dry periods). While total average annual rainfall may decrease, rainfall is predicted to occur in fewer, more intense precipitation events. The combination of a generally drier climate in the future, which will increase the chance of drought and wildfires, and the occasional extreme downpour is likely to cause more mudslides and landslides.<sup>135</sup>

In addition, the increased wildfire occurrence also escalates the risk of landslide and debris flows in the period following a fire, when slopes lack vegetation to stabilize soils<sup>136</sup> and burned soil surfaces create more rainfall runoff. As climate change affects the length of the wildfire season, it is possible that a higher frequency of large fires may occur into late fall, when conditions remain dry, and then be followed immediately by intense rains early in the winter, as occurred with the Thomas Fire in December 2017 and subsequent Montecito and Carpinteria debris flows in January 2018.

### 6.2.3 ASSESSMENT OF LANDSLIDE VULNERABILITY AND POTENTIAL LOSSES

The impact of natural hazards on the built environment generally depends on exposure (proximity to the hazard and its severity) and the vulnerability of engineered structures (structure type, design, and age). The closer a structure is to a hazard event, the more damage that is likely to be sustained, while the larger a hazard event is, the greater its impact at a given distance. Brick buildings resist storm and fire damage better than wood construction; however, these buildings – particularly unreinforced masonry – are less resilient against earthquakes. The resistance a structure of a given type will have against natural hazards depends on the building code in effect at the time of construction and how closely its provisions are followed.

Codes improve with time, so newer construction generally performs better than older construction. While structures can be designed to resist the forces of gravity, wind, and earthquakes, it is not economically feasible to design structures to resist the large earth movements that can accompany large landslides. Landslide losses primarily result

<sup>135</sup> CNRA, 2009; California Climate Change Center, 2009

<sup>136</sup> California Department of Natural Resources. Safeguarding California: Implementation Action Plans. 2016. Sacramento: author, 279 p.

from hazard exposure (high population densities in mountainous terrain), however, rather than inferior structural design.

The two main types of structures that are vulnerable to landslides are buildings and utility/transportation lifelines. Table 6.K lists notable landslides and debris flows in California.

**Typical Landslide damage to Homes Caused by Intense Ground Deformation of the Landslide Mass in Anaheim Hills, Orange County, 2005. (The slow movement of the slide allowed residents to evacuate.)**



### **Buildings**

Landslides directly damage engineered structures in two general ways: 1) disruption of structural foundations caused by differential movement and deformation of the ground upon which the structure sits, and 2) physical impact of debris moving downslope against structures located in the travel path. As a landslide breaks away from a slope and moves, it deforms the ground into an undulating, hummocky surface broken up by fissures and scarps.

When situated on top of a landslide, the deformation distresses structural foundations, and the structures themselves, by settlement, cracking, and tilting. This can occur slowly, over years, or rapidly within days or hours. Water-saturated, fast-moving debris flows (called “mudslides” by the media) can destroy everything in their path, collapsing walls and shifting structures off their foundations. The 2005 La Conchita Landslide in Ventura County traveled with such force that it destroyed 30 homes, scraping many off their foundations and piling them, one on top of another, three high.

**Table 6.K: Notable Historic Landslides and Debris Flows in California**

Location	Year	Impact <sup>a</sup>
Montecito	2018	Post-Thomas Fire debris flows. 129 homes destroyed, 307 homes damaged, 21 fatalities.*
Camarillo Springs	2014	Post-Springs Fire debris flows. 10 homes destroyed, 6 homes damaged.
La Canada	2009-2010	Post-Station Fire debris flows with early damage claims at \$58 million and Los Angeles County cleanup costs at over \$30 million (2009 dollars).
Pacifica	2007	Devil's Slide: bypass construction of \$325 million (See: San Francisco Chronicle).
La Conchita	2005	30 homes destroyed, 10 fatalities.
Laguna Beach	2005	18 homes destroyed, 8 homes damaged. Slide repair cost: \$21 million. Cost of damage: \$35 million.
San Bernardino	2003	Post-Grand Prix/Old Fire debris flows on Christmas Day. 16 fatalities, 52 homes and 32 trailers damaged; more than \$100 million in damages.
Mission Peak	1998	--
Laguna Niguel	1998	9 homes and 57 condominiums destroyed. \$12 million awarded to homeowners in lawsuit; \$16 million to stabilize slope <sup>b</sup>
Rio Nido	1998	37 homes destroyed. 140 residents evacuated <sup>c</sup>
Laguna Beach	1998	18 homes destroyed, damaged 300 others. Two fatalities.
El Dorado County Hwy 50	1997	Destroyed Highway 50; \$32 million in repair and economic losses. <sup>i</sup>
La Conchita	1995/2005	6 homes destroyed. <sup>e</sup>
Anaheim Hills	1993	30 homes destroyed, 200 homes damaged. Cost: \$12 million.
Bay Area	1982	Debris flows and landslides on private and public property Cost: \$172 million <sup>j</sup>
Big Rock Mesa	1979/1983	13 homes destroyed. Cost: \$114 million. Damage to Highway 1 cost: \$1.26 billion <sup>f</sup>
Laguna Beach	1978	19 homes destroyed, 45 homes damaged. Cost: \$62 million <sup>g</sup>
San Fernando	1971	Cost: \$354 million
Saugus-Newhall	1971	Cost: \$312 million
Palos Verdes	1956, intermittently	More than 100 homes severely damaged or destroyed. Cost: \$34 million; \$68 million in damage settlements <sup>h</sup>

Source: California Geological Survey, or as noted

<sup>a</sup>Dollar amounts are adjusted to 2006 dollars

<sup>b</sup><http://anaheim-landslide.com/laguna.htm>

<sup>c</sup><http://www.sonoma.edu/geology/wright/rioslide.htm>

<sup>d</sup><http://wrqis.wr.usgs.gov/wgmt/elnino/scampen/laguna/index/html>

<sup>e</sup>[http://www.geog.ucsb.edu/~jeff/projects/la\\_conchita/apcq2001\\_article/apcq2001\\_article.html](http://www.geog.ucsb.edu/~jeff/projects/la_conchita/apcq2001_article/apcq2001_article.html)

<sup>f</sup><http://www.ci.malibu.ca.us/download/index.cfm?fuseaction=download&cid=3144>

<sup>g</sup>[http://www.consrv.ca.gov/cgs/geologic\\_hazards/landslides/Bluebird%20Canyon%20Landslide%20Cover.pdf](http://www.consrv.ca.gov/cgs/geologic_hazards/landslides/Bluebird%20Canyon%20Landslide%20Cover.pdf)

<sup>h</sup>[http://seis.natsci.csulb.edu/VIRTUAL\\_FIELD/Palos\\_Verdes/pvportuguese.htm](http://seis.natsci.csulb.edu/VIRTUAL_FIELD/Palos_Verdes/pvportuguese.htm)

<sup>i</sup>[http://www.conservation.ca.gov/cgs/rghm/landslides/cal\\_geology/Documents/1997%20hwy%2050%20cal%20geology.pdf](http://www.conservation.ca.gov/cgs/rghm/landslides/cal_geology/Documents/1997%20hwy%2050%20cal%20geology.pdf)

<sup>j</sup>USGS pp 1434; [ftp://ftp.consrv.ca.gov/pub/dmg/pubs/cg/1982/35\\_07.pdf](ftp://ftp.consrv.ca.gov/pub/dmg/pubs/cg/1982/35_07.pdf)

\*Based on preliminary incident data available February 2018

**The 2018 Montecito Debris Flow in Santa Barbara County Engulfs a Home Near San Ysidro Creek**

Source: Jeremy Lancaster, California Geological Survey

**Utilities and Transportation**

In addition to buildings, utilities and transportation structures are vulnerable to the impact and ground deformation caused by slope failures. They present a particular vulnerability because of their geographic extent and susceptibility to physical distress. Lifelines are generally linear structures that, because of their geographic extent, have a greater chance of being affected by ground failure (hazard exposure).

Extension, bending, and compression caused by ground deformation can break lifelines. Failure of any component along the lifeline can result in failure to deliver service over a large region. Once broken, transmission of the commodity through the lifeline ceases, which can have catastrophic repercussions down the line: loss of power to critical facilities such as hospitals, impaired disposal of sewage, contamination of water supplies, disruption of all forms of transportation, release of flammable fuels, and so on. Therefore, the overall impact of lifeline failures, including secondary failure of systems that depend on lifelines, can be much greater than the impact of individual building failures.

The cost of damage to lifelines is a substantial part of the overall social impact. Studies have shown that Caltrans spends an average of \$50 million per year repairing and mitigating landslide damage. Other lifeline operators (local governments and utilities) may spend a similar amount.

The economic impact of landslide damage to lifelines can be much greater than direct repair costs, but there are no estimates of the total indirect costs. In one illustrative example, the 49-year old Highway 1 Pfeiffer Canyon Bridge just south of Big Sur Station in Monterey County was demolished by Caltrans in March 2017 due to irreparable damage to the bridge columns caused by landslide movement under the bridge foundation as a result of heavy winter rains. The new bridge replacement, which Caltrans completed 2017, cost \$24 million.

Another significant Big Sur landslide triggered by heavy winter and spring rains is the May 2017 Mud Creek Slide which buried a quarter mile section of scenic Highway 1 approximately 9 miles north of the San Luis Obispo-Monterey County line. Caltrans estimates that over 1 million tons of rock and dirt fell during the slide, which is actually a combination of five slides. The affected section of Highway 1 was covered by a layer of dirt and rock about 35 to 40 feet deep. The section of Highway 1 closed by the slide re-opened in July 2018.

Following the 1997 Mill Creek Slide on Highway 50, the CGS began development of highway corridor landslide maps to assist Caltrans. Development of these maps for various highway corridors continued for over a decade, and the maps are posted on the CGS website. To find out more about the history of the program or to view maps, visit: <http://www.conservation.ca.gov/cgs/rghm/landslides>.

In January 2018, the catastrophic Montecito post-fire debris flow discharged a volume of material so large that an approximate 10-mile portion of Highway 101 was closed for about two weeks while Caltrans and other state agencies worked to remove mud, boulders, trees, utility poles, and other debris. The debris flow was so powerful that mud and debris, including vehicles, were deposited onto beaches, necessitating the closure of eight Santa Barbara County beaches to protect public health. The debris flow also caused significant damage to utilities, including substantial damage to water mains and complete removal of utility poles. This utility damage left some Montecito residents and businesses without gas, power, and water services for close to two weeks.

#### **Boulders Deposited in a Montecito Roadway During the Post-Fire Debris Flow, January 2018**



*Source: Mike Eliason/Santa Barbara County Fire Department*

## 6.2.4 CURRENT LANDSLIDE HAZARD MITIGATION EFFORTS

Exposure to landslide hazards can be reduced by effective land use planning and hillside development practice. Like slope steepness and material strength, potential for water-saturated hillsides (or earthquake shaking) is a design parameter that should be considered when preparing a building site. Reducing landslide hazard is accomplished by either reducing gravity forces acting on a slope by grading to decrease steepness, or increasing slope resistance and restraint using structural systems and effective dewatering and drainage. If either approach is not economically viable for a particular project, avoiding the hazard by relocating the project to a safer site is the alternative. Landslides that affect existing structures can often be stabilized using engineering resistance and retention systems and effective dewatering that strengthen the slope and hold rock/soil mass in place.

### Local Government Responsibilities

Managing landslide risk is primarily the responsibility of local governments where planning and building departments serve as lead agencies. Over 80 percent of California cities have landslide/mudslide ordinances, design standards, or guidelines for hillside development. California's Seismic Hazards Mapping Act designates landslide zones wherein cities and counties are required to condition construction permits upon adequate landslide site investigation and agreed-upon mitigation. These efforts have proven effective in reducing losses over the past decades, but not all jurisdictions that face potential landslide hazards have such instruments, nor has zoning of all landslide-prone areas been completed under the state program.

### California Landslide Hazard Mapping

Since the 1970's, the California Geological Survey (CGS) has produced numerous maps that show landslide features and delineate potential slope-stability problem areas. Preparation of these maps has been episodic, often driven by landslide disasters and subsequent legislative mandates. Many CGS landslide maps and related products have been produced for local or state agencies in response to their specific needs.

California's Landslide Hazard Identification Act established the Landslide Hazard Identification Program (LHIP) in 1986 under the jurisdiction of the CGS, which prepared maps of landslide hazards and distributed them to local governments. Since the LHIP terminated by sunset law in 1995, some landslide hazard identification mapping is being conducted under the Seismic Hazards Mapping Act. However, there has been no state program to evaluate or map the types of landslides that cause the most casualties. Although the Alluvial Fan Task Force provided some guidance on where runout could affect developing areas in southern California, the need for a statewide assessment of debris flow potential on hillsides and alluvial fans is not being met.

#### Progress Summary 6.M: Landslide Hazard Mapping

**Progress as of 2018:** The California Geological Survey (CGS) has released maps of zones of requiring investigation for seismically induced landslides under the Seismic Hazards Mapping Act since 1997. In addition, the CGS has been producing maps of landslides since the 1970s.

The CGS is in the process of digitizing maps of landslides, and hundreds of these landslide inventory maps, covering much of coastal California, are now available on the CGS Landslide Inventory Viewer:

<http://maps.conservation.ca.gov/cgs/informationwarehouse/index.html?map=landslides>.

The map viewer index includes landslide maps produced over many years and for a variety of purposes. Mapping of landslides reflects the standards of the project and time the map was prepared. The amount of information recorded about each landslide has increased over time, so more information is available for more recently mapped landslides. Updates to the database are continuing, both to include more existing maps and to add current landslides as they occur. The Landslide Inventory Viewer is a work in progress and is being updated continuously as the CGS produces new maps, adds more information, and corrects existing maps.

The CGS prepares four main types of landslide maps:

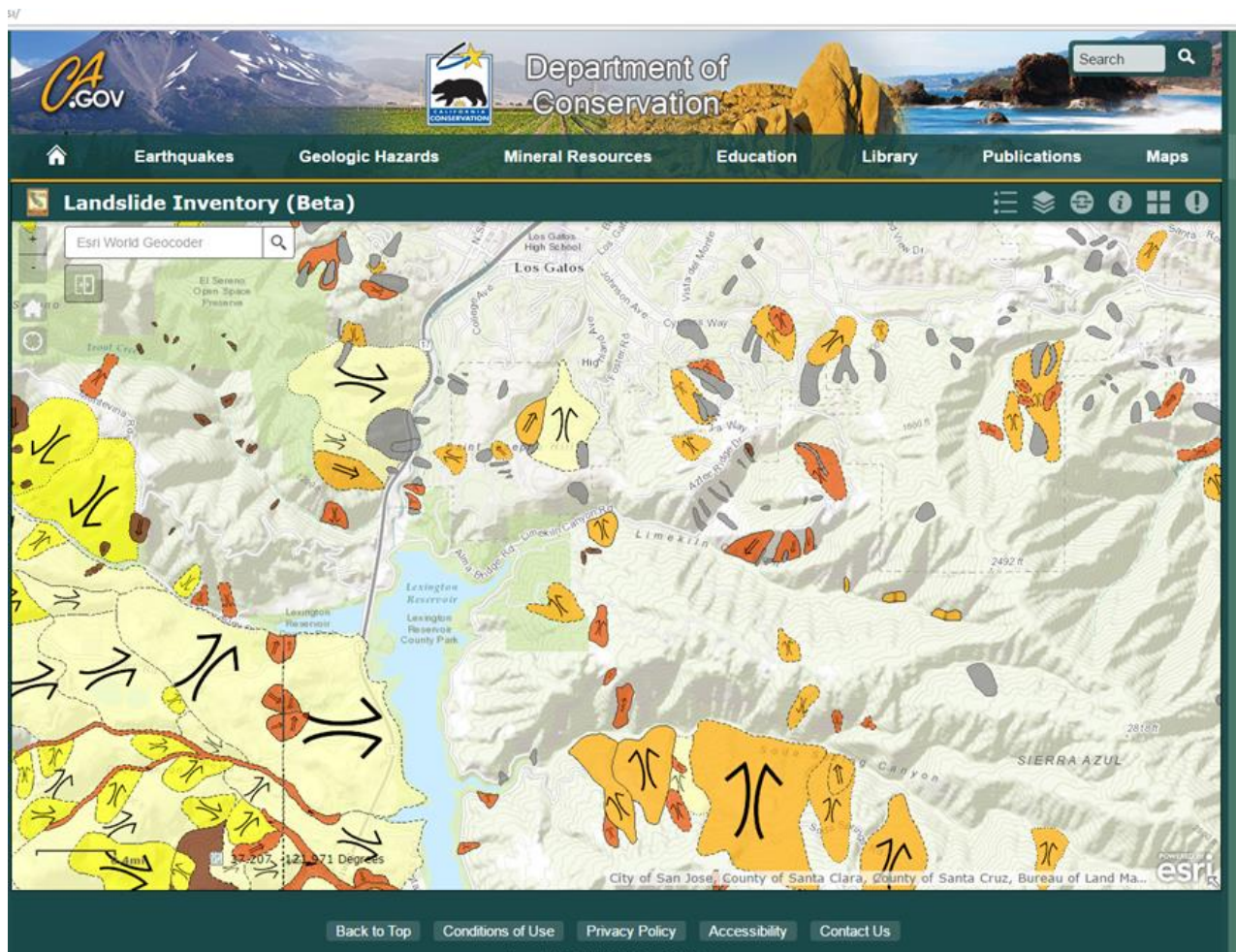
1. Landslide-inventory maps
2. Landslide-hazard maps
3. Landslide-risk maps
4. Landslide-zone maps

For a more detailed discussion on the types of CGS landslide maps, current CGS mapping programs, and the history of CGS landslide mapping, visit:

[http://www.conservation.ca.gov/cgs/geologic\\_hazards/landslides/Pages/Index.aspx](http://www.conservation.ca.gov/cgs/geologic_hazards/landslides/Pages/Index.aspx).

Maps showing the locations of existing landslides in a community are useful for land use decision-making because they target areas to be avoided or remediated before construction can safely proceed. The maps indicate not only the location, but also activity status and direction of slope movement to provide a better understanding of where landslides are most likely to be triggered, either by winter storms or earthquakes. Because of the value of landslide maps for hazard mitigation projects, many communities have prepared such maps as part of the safety elements of their general plans or for Local Hazard Mitigation Plans. Advanced knowledge of slope instability can help to assure that proper consideration will be included in grading plans and that safe foundations will be constructed.

**Map 6.BB: California Geological Survey Landslide Inventory Viewer – Showing Los Gatos/Highway 17 Area**



Source: CGS

Map 6.BB is an example of a landslide inventory map from CGS' landslide map viewer showing boundaries of existing landslides in a portion of the Los Gatos/Highway 17 area. Landslides mapped by CGS and other are shown as colored areas when data is available. The background yellow-red colors indicate areas of weak rocks and/or steep slopes leading to susceptibility to deep landslides. Darker red as background indicates higher susceptibility. Landslides are color-coded as Active or Historic Movement (brown), Dormant – Some Indication of Historic Movement (orange), and Dormant – Old, No Evidence of Historic Movement (yellow). Arrows show direction of landslide movement. When using the viewer online great detail can be viewed by zooming in.

### **Landslide Predictive Modeling and Preliminary Site Assessment**

In response to recommendations made by the Alluvial Fan Task Force, the CGS collaborated with the California Department of Water Resources (DWR) to conduct a post-fire runoff assessment study culminating in a 2014 report entitled the "Assessment of Post-Fire Runoff Hazards for Pre-Fire Mitigation Planning – Southern California."<sup>137</sup> The study was funded by FEMA's Hazard Mitigation Grant Program.

The purpose of the study was to use regional-scale predictive models to assess potential effects of post-fire runoff from a pre-fire planning perspective. The study assessed watersheds under a range of possible rainfall and burn conditions, with the resulting data to be used by floodplain managers and emergency responders in developing mitigation actions and response plans. Regional model results provide information for use in hazard mitigation planning by highlighting watersheds prone to potentially hazardous post-fire runoff events and providing a range of results under different scenarios. This information allows floodplain managers and emergency responders to set priorities for hazard mitigation.

Regional modeling of burn areas around the state is being conducted by state and federal agencies that respond to post-fire hazards, to assess post-fire conditions for risk from debris flows that could affect vulnerable areas. A copy of the report can be downloaded at the following link:

[ftp://ftp.consrv.ca.gov/pub/dmg/pubs/sr/SR\\_234/CGS\\_SR234\\_Final\\_v1.pdf](ftp://ftp.consrv.ca.gov/pub/dmg/pubs/sr/SR_234/CGS_SR234_Final_v1.pdf).

In 2015 CGS prepared a special publication guiding assessment of alluvial fan depositional environments to determine areas that may be impacted by alluvial fan flooding. The publication provides direction for regional planning including:

- Data requirements
- Mapping standards
- Clarification of terminology
- Information for preliminary design

For a copy of this report, contact CGS at: [cgspubs@consrv.ca.gov](mailto:cgspubs@consrv.ca.gov).

For more information about USGS assessment of post-fire debris-flow hazards, visit the following webpage:

[https://landslides.usgs.gov/hazards/postfire\\_debrisflow/index.php](https://landslides.usgs.gov/hazards/postfire_debrisflow/index.php).

### **Watershed Emergency Response Team Post-Wildfire Debris Flow and Flood Assessments**

Following selected wildfires, California, in coordination with federal agencies, deploys Watershed Emergency Response Teams (WERTs) to conduct post-fire assessments. The WERT assessments identify types and locations of threats to life-safety and property (i.e., collectively known as "values-at-risk" or VARs) from debris flows, flooding, rockfall, and erosion that are elevated due to wildfire. As part of the WERT assessment, the team develops preliminary emergency protection measures for the identified locations in a detailed report with maps, and communicate the findings to responsible emergency management agencies.

---

<sup>137</sup> CGS Special Report 234 and Alluvial Fan Flooding SR227

WERT post-fire assessments are generally limited to large wildfires that pose significant threat to lives and property from post-fire debris flows and flooding. While similar in some ways to U.S. Forest Service's Burned Area Emergency Response (BAER) Team assessments, the WERT assessments have less emphasis on natural and cultural resources and only recommend emergency measures for life-safety and property protection.

Most wildfires, including small fires, fires located mostly on federal lands, fires in areas with short gentle slopes or low landslide potential, and fires not in proximity to housing developments or other VARs, typically do not require a WERT assessment. (Note: fires greater than 500 acres on U.S. Forest Service lands trigger a separate BAER assessment.) WERT assessments are typically established based on the recommendation of the CAL FIRE director, unit chief, IMT incident commander, unit forester. A federal or state disaster declaration may also make WERT deployment more likely.

When making the determination to deploy the WERT for post-fire assessment work, the following key factors are considered:

- The presence of life-safety-related VARs (e.g., homes, businesses, other infrastructure) downslope and/or downstream of steep hillslopes and catchments burned at moderate to high soil burn severity.
- High likelihood of debris flows and flooding based on soil burn severity, topography, geology, and likely rainfall rates.
- Historical occurrence of debris flows and flooding during burned and/or unburned conditions.
- Presence of transportation networks (e.g., highways, rail lines), water supply systems, power generating plants and conveyance systems, campgrounds/resorts, and other high value sites expected to be at high risk due to post-fire debris flows and flooding.
- A high percentage of SRA included in the fire area.

WERT assessments are a collaborative effort between primary agencies and other additional agencies, which require interagency cooperation at the state, federal, and local level. Primary agencies include California Department of Forestry and Fire Protection (CAL FIRE), California Geological Survey (CGS), California Department of Water Resources (DWR), and U.S. Geological Survey (USGS). Additional agencies may include the Regional Water Quality Control Boards (RWQCBs), Natural Resources Conservation Service (NRCS), and local jurisdictions. CAL FIRE acts as the lead agency coordinating the WERT in cooperation with all contact agencies. Specialized personnel with qualifications in engineering geology, civil engineering, hydrology, GIS, forestry (including fire line safety), and water quality are required to rapidly identify life-safety hazards. Which specific agencies are involved in a WERT assessment and the size of the team typically depends on the size and complexity of the fire and post-fire threats. Team size can range from one to twenty individuals. CAL FIRE provides the funding for agency involvement through MOUs and other pending agreements.

When a WERT assessment is determined to be necessary, the process involves the following steps:

- Assemble an interdisciplinary team of engineering geologists, civil engineers, hydrologists, foresters, soil scientists, GIS specialists, and others, as required.
- Meet with county and/or city officials and others with local knowledge of potential high risk locations within or downstream of the fire area.
- Obtain the satellite-derived burned area reflectance classification (BARC) map indicating preliminary burn severity and field verify soil burn severity determinations shown on the map.
- Submit the field verified soil burn severity map to the U.S. Geological Survey (USGS), allowing their scientists to produce the debris flow model basin and segment probability map using a 15-minute rainfall intensity design storm event. USGS debris flow model results are presented in terms of combined hazard, reflecting both the probability of debris flows and the magnitude of potential debris volume.
- Conduct flood modeling and calculate debris volumes for specific watersheds located above identified VARs.
- Conduct surface erosion modeling before and after the fire.
- Compile all collected data and modeling results as GIS layers and load them on to tablets and smart phones for field use.
- Determine the location of potential VARs within and downstream of fire perimeter.

- Field check and record VAR locations digitally as points or polygons and develop preliminary emergency protection measures.
- Summarize VAR information in a detailed Excel table and GIS map format and compile a draft report documenting the physical setting, methods utilized, modeling results, general and specific observations, and general recommendations.
- Conduct a meeting with local emergency response agencies to present the draft report findings and answer questions regarding report information and recommendations.
- Following review of the draft report by senior CAL FIRE and CGS staff, the report is finalized and approved by CAL FIRE, posted on CAL FIRE’s website, and distributed to local agencies and other contacts made during the field investigation.

The field assessment process typically takes between one and two weeks, with additional time required for draft report generation and agency approval. Following completion of the report, conducts a WERT closeout meeting with local governments to go over the findings of the WERT field assessment process and the identified VARs. Once the closeout meeting is completed, Cal OES assembles the Post-Fire Watershed Task Force. The Cal OES-led Post-Fire Watershed Task Force coordinates with local county offices of emergency services and other state and federal agencies to facilitate and support implementation of VAR emergency protection measures and mitigation projects.

Typical WERT recommended emergency protection measures include:

- Early warning systems—cell phone warnings using National Weather Service flash flood and post-fire debris flow “watch” and “warning” notifications for burned areas based on radar-derived forecasts
- Storm patrols—monitor road drainage infrastructure during strong storm events
- Structure protection/debris barrier—installation of k-rails, sandbags, silt fences, temporary culverts, straw bale check dams, muscle walls, etc., where appropriate
- Debris clearance—monitor and/or remove debris from debris basins, and from within channels subject to post-fire flooding
- Notification—post temporary signage in areas of potential hazard
- Closure of high risk areas—close areas such as campgrounds during strong storm events
- Emergency Action Plans—encourage local agencies to develop EAPs for very high risk VARs potentially impacting large numbers of people
- Improved agency communication--when appropriate encourage local flood control and public works departments to assist in communicating the high potential and high risk/consequences of post-fire watershed hazards to local emergency management agencies

Where wildfires include both federal and non-federal lands and an assessment is determined to be necessary, WERT and BAER teams work closely and collaboratively to share data and avoid redundant efforts. From 2015 to August 2018, WERT was deployed 16 times, including following the North Bay wildfires in 2017, the Thomas Fire in January 2018, and the Carr Fire and Holy Fire in the summer of 2018. Final WERT reports are posted on the CAL FIRE website.

In many cases, local jurisdictions may be able to obtain funding for some longer-term VAR emergency protection measures or mitigation projects from the FEMA Hazard Mitigation Assistance Program (HMA), either through a Hazard Mitigation Grant Program (HMGP) or Public Assistance (PA) grant. HMGP grants that prioritize shovel-ready wildfire/watershed mitigation projects or other post-wildfire mitigation activities or PA grants that prioritize immediate threat erosion control measures to address post-wildfire soil conditions may be applicable sources of funding for eligible VAR emergency protection measures and mitigation projects by local jurisdictions. Additionally, emergency management agency coordination with NRCS may be appropriate, since funding for post-fire recovery measures for exigent work may be available under NRCS’s Emergency Watershed Protection (EWP) Program.

### **Flash Flood and Debris-Flow Demonstration Early Warning System**

In Southern California, the USGS has identified the rainfall conditions required to trigger post-wildfire debris flows. Based on that data, the National Oceanic and Atmospheric Administration (NOAA) and the USGS have established a demonstration flash flood and debris-flow early warning system for recently burned areas covering eight counties in Southern California.

The early warning system uses the National Weather Service (NWS) Flash Flood Monitoring and Prediction (FFMP) system. The FFMP system identifies when both flash floods and debris flows are likely to occur based on comparisons between radar precipitation estimates and established rainfall intensity-duration threshold values.

When predicted rainfall rates exceed defined thresholds, the early warning system is triggered to send advisories, watches, and warnings to regional emergency management personnel using the NWS Advanced Weather Information Processing System. This information can then be disseminated to local residents to give warning of potential of landslide risks or evacuation requirements.

This demonstration system improves on former warning systems that were based on local precipitation tracking and were not able to trigger alerts with sufficient lead time for evacuation.

For more information regarding the demonstration early warning system and participating Southern California counties, visit the program web page: <https://landslides.usgs.gov/hazards/warningsys.php>.

The following links provide information on early warning progress for the NOAA-USGS Flash Flood and Debris Flow Early Warning System: [http://www.wrh.noaa.gov/lox/main.php?suite=hydrology&page=debris-flow\\_project](http://www.wrh.noaa.gov/lox/main.php?suite=hydrology&page=debris-flow_project) and <https://pubs.usgs.gov/fs/2005/3104/>.

**Best Practices Highlight 6.H: Devil's Slide Tunnel Project**

Devil's Slide, located on the coast of California between the cities of Pacifica and Montara, is described by the California Department of Transportation (Caltrans) as "an unstable ocean-facing cliff highly prone to rock falls and slippage."<sup>138</sup> Since original construction of State Route 1 across the steep, geologically unstable cliff in the 1930s, ongoing landslides have caused safety problems as well as closures along this stretch of highway. Starting with a major landslide event in 1940 that destroyed much of the road, intermittent landslides occurring during winter storms have resulted in an ongoing periodic cycle of costly reconstruction and destruction.

In the late 1950s, a possible highway bypass route to Devil's Slide was identified but opposed by concerned groups due to potential environmental impacts. In the 1990s, a tunnel alternative was determined to be reasonable and feasible, leading to voter approval of the Devil's Slide Tunnel Initiative (Measure T) in 1996. This initiative amended the Local Coastal Plan to include the tunnel project as the only feasible highway bypass option for State Route 1 at Devil's Slide. Following completion of the environmental review process, ground breaking for construction of the tunnels occurred on May 6, 2005.

Boring of the tunnels started in September 2007 and was completed in 2011. The tunnel project consists of the following elements: 1) new realignment along State Route 1, 2) two parallel 4,000-foot-long tunnels, 3) two parallel 1,000-foot-long bridges at the north portal approach, 4) an operations and maintenance center south of the tunnels, and 5) public access features for hikers and bicyclists. As part of the project, Caltrans has handed over control of the bypassed portion of the road and 70 nearby acres to San Mateo County for use as a public park.

The tunnels, officially named the Tom Lantos Tunnels after late congressman Tom Lantos, opened to traffic in March 2013. The tunnels are the first to open in California in almost 50 years. By creating a bypass around the geologically unstable slide area, the tunnel project has mitigated safety problems and avoided costly future repairs and the risk of permanent failure of the State Route 1 roadway. More information about the tunnel project can be found at: <http://www.dot.ca.gov/dist4/dslide/>

**Devil's Slide Tunnel Project Schematic by CalTrans**

Source: California Department of Transportation website: <http://www.dot.ca.gov/dist4/dslide/>

<sup>138</sup> Devil's Slide Fact Sheet, California Department of Transportation

## 6.3 VOLCANO HAZARDS, VULNERABILITY, AND RISK ASSESSMENT

*“California is the most geologically diverse state in the nation. We are known for our earthquakes, landslides, and flood hazards. But a nearly forgotten hazard is our volcanoes”* John Parrish, State Geologist of California, February 9, 2012

Many of California’s young volcanoes pose a threat to people and property. Volcanic eruptions occur in the state about as frequently as the largest San Andreas Fault Zone earthquakes; at least ten eruptions have occurred in California in the last 1,000 years and the likelihood of renewed volcanism in the state is on the order of 1 in a few 100 to 1 in a few thousand annually. A new effort to identify, prepare for, and mitigate volcanic hazards within California is underway. The California Governor’s Office of Emergency Services (Cal OES), the United States Geological Survey California Volcano Observatory (USGS CalVO), and the California Geological Survey (CGS) are working in partnership to produce the first statewide assessment of California’s exposure and vulnerability to future volcanic hazards.

### 6.3.1 IDENTIFYING AND PROFILING VOLCANO HAZARDS

A national report on volcanic threat published by the USGS in 2005 lists 15 young and potentially hazardous volcanic areas in California.<sup>139</sup> Volcanic threat rankings are derived from a combination of factors including age of the volcano, potential hazards (the destructive natural phenomena produced by a volcano), exposure (people and property at risk from the hazards), and current level of monitoring (real-time sensors in place to detect volcanic unrest). Threat rankings are periodically re-evaluated, and revised if necessary, as ongoing research provides new information on potential hazards or societal exposure.

As shown in Map 6.CC, California’s Very High, High, and Moderate threat volcanoes include Medicine Lake Volcano, Mount Shasta, Lassen Volcanic Center, Clear Lake Volcanic Field, Long Valley Volcanic Region, Ubehebe Craters, Coso Volcanic Field and Salton Buttes. Seven other young volcanoes in California with lower threat ranking are identified in the 2005 report, including Brushy Butte, Twin Buttes, Tumble Buttes, and Silver Lake Volcanic Field, Eagle Lake Volcanic Field, Golden Trout Creek Volcanic Field, and Lavic Lake Volcanic Field.

#### Types of Volcano Hazards

A variety of hazard types accompany volcanic eruptions, as shown in Figure 6.C. *Explosive volcanic eruptions* blast lava fragments (*tephra*) and gas into the air with tremendous force from the volcanic *vent*. The finest particles, called *volcanic ash*, billow upward, forming an eruption column that can attain stratospheric heights in minutes. Simultaneously, searing volcanic gas laden with ash and coarse chunks of *lava* may sweep down the flanks of the volcano as a *pyroclastic flow*, and *ballistics*, chunks of solid rock or partially molten lava, may come crashing down around the vent. Ash in the eruption cloud, carried by the prevailing winds, may remain suspended for hundreds of miles before settling to the ground.

During less energetic *effusive eruptions*, hot, fluid lava may gush out of the volcano as lava flows that can cover many miles in a single day. Alternatively, a sluggish plug of cooler, partially solidified lava may slowly push up through a crack during an effusive eruption, creating a *lava dome*. A growing lava dome may become so steep that it collapses, explosively releasing pyroclastic flows potentially as hazardous as those produced during explosive eruptions.

<sup>139</sup> <http://pubs.usgs.gov/of/2005/1164/>

Map 6.CC: Potentially Hazardous Volcanoes of California



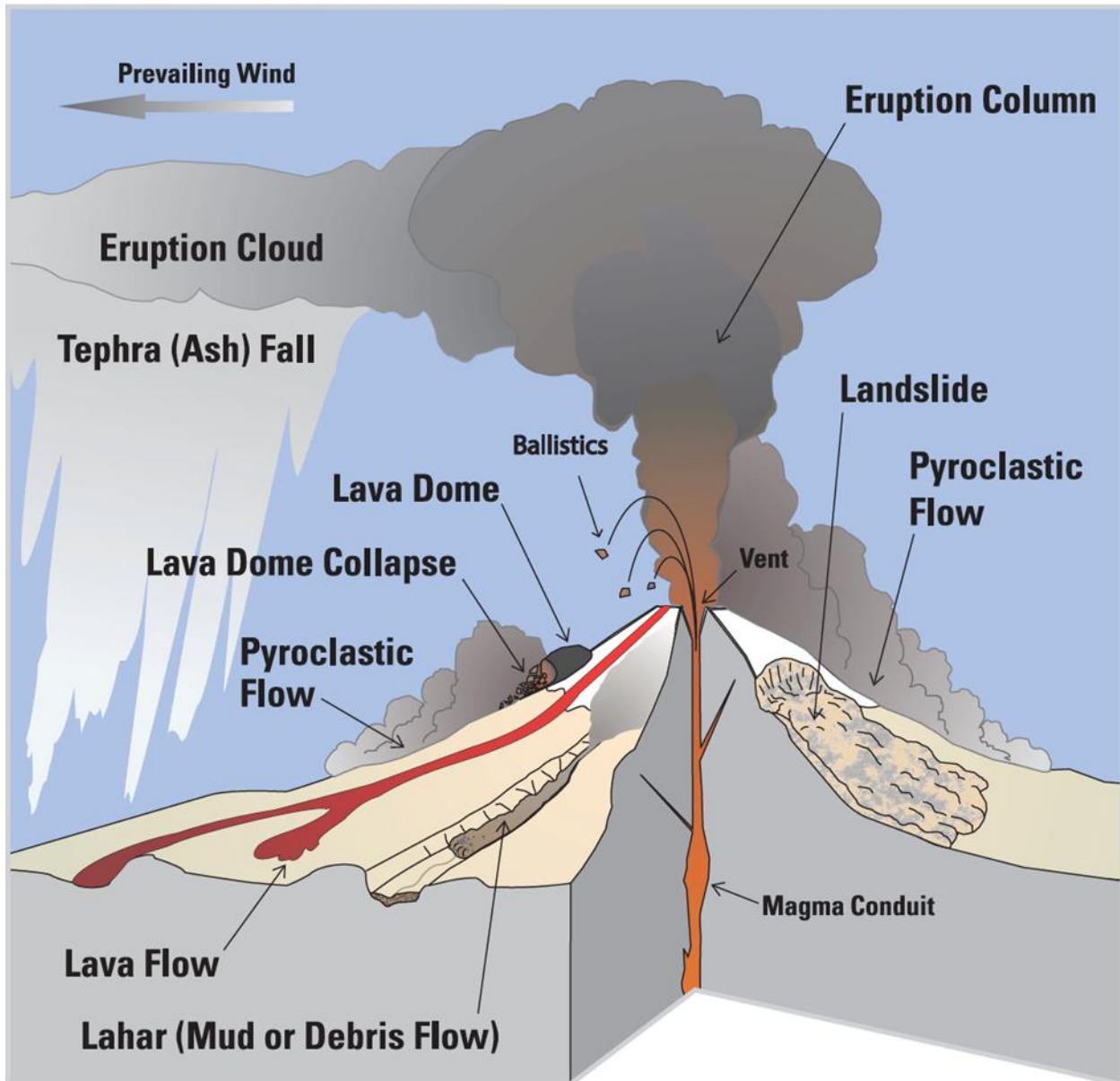
Source: U.S. Geologic Survey, Cal OES

Map 6.CC depicts California’s young Low, Moderate, High, and Very High Threat volcanoes. See: <https://pubs.usgs.gov/fs/2014/3120/downloads/fs2014-3120.pdf>.

During and after an explosive or effusive eruption, loose volcanic debris on the flanks of the volcano can be mobilized by heavy rainfall or melting snow and ice, forming powerful floods of mud and rock (*lahars*) resembling rivers of wet concrete. These can rush down valleys and stream channels, destroying roads and bridges and carrying away entire buildings. Flooding can also occur due to melting of ice and snow by volcanic heat or by diversion of streams blocked by volcanic debris.

Low-energy effusive eruptions are destructive, but generally not life threatening. High-energy explosive eruptions are both destructive and life threatening. Volcanic areas can be hazardous even when the volcano is not erupting, with unstable ground, noxious gas emissions, intense heat, and steaming ground.

**Figure 6.C: Volcano Hazard Components**



Source: U.S. Geological Survey, Cal OES

Figure 6.C depicts the range of volcanic hazards that could accompany the next eruption in California. It is unlikely, however, that a single eruption would produce all hazards depicted. See: <https://pubs.usgs.gov/fs/fs002-97/>.

Eruption hazards are most severe within a few miles of the vent with life-threatening and/or highly destructive phenomenon evolving rapidly, often within seconds to minutes, leaving little time to mount evasive actions. Generally, hazard severity declines and the time available to issue warnings increases as distance from the vent increases.

Timely warnings reduce the risk of fatalities, but depending on hazard type, destruction and/or societal disruption can extend many tens of miles from the volcano. In addition, some hazards endure well beyond the timescale of the eruption. Post eruption hazards—rain remobilized lahars, re-suspended ash, and seeping volcanic gas—may disrupt human activities or cause annoyances for years, even decades after an eruption has stopped.

Table 6.L outlines the potential impact of particular types of hazards associated with California volcanoes.

**Table 6.L: Characteristics and Potential Impacts of California Volcanic Hazards**

Hazard Profile	Characteristics	Impact
<b>Pyroclastic Flow</b>	Sudden eruption of hot (400-1300°F), gas-pressurized flows of ash and lava fragments that rush outward from the volcano with great force at ground speeds greater than 50 miles per hour (mph). Pyroclastic flows typically follow valleys but can overtop ridges and travel 30 miles or more from the volcano.	Pyroclastic flows travel much too fast for people to outrun, and are thus a main cause of eruption-related fatalities. Flows knock down, shatter, bury, or carry away nearly all objects and structures. Extreme temperatures burn forests, crops, buildings, furnishings, and vehicles.
<b>Lava Flow</b>	Gradual inundation by lava from sustained low-level eruptions moving at speeds of less than 30 mph. Lava may pile up near the vent in thick mounds (lava dome), or move across the landscape for many kilometers as fluid rivers of molten rock.	Everything in the path of slow speed lava flows will be knocked down, buried, or burned. The flows generally travel slowly enough that people, possessions, and transportable infrastructure can be moved out of the way. The flows often ignite wildfires, and areas inundated by flows can be buried by 10 feet or more of hardened rock, making it impossible to rebuild or repair structures.
<b>Lahars</b>	Slurry-like floods of volcanic ash, rock, and water that look like wet concrete. Debris flows gain momentum during travel by eroding and entraining soil and loose rock debris from channels. Large debris flows may carry boulders 30 feet across and travel through valleys and stream channels at speeds of 20 to 40 mph. Debris flows can be hot, with temperatures close to boiling. They occur during an eruption due to melting snow or ice, or after an eruption due to re-mobilization of loose volcanic deposits during intense rainfall.	Most debris flows travel much too fast for people to outrun, and are thus a main cause of eruption-related fatalities. Debris flows can destroy buildings and bridges, and bury vast areas with deposits of mud and rock up to 160 feet thick as far as 65 miles from the volcano.

Hazard Profile	Characteristics	Impact
<b>Ash Fall</b>	Fine fragments of lava, sand size and smaller, deposited from drifting ash clouds. Impact zone may be many tens to a few hundreds of miles from the volcano.	Although generally non-lethal, fine ash fall is the most widespread and disruptive volcanic hazard. People exposed to fine ash commonly experience various eye, nose, and throat symptoms. Short-term exposures are not known to pose a significant health hazard. Long-term health effects have not been demonstrated conclusively. Ash deposited downwind of the volcano covers everything like a snowfall, but also infiltrates cracks and openings in machinery, buildings, and electronics. Falling ash can obscure sunlight, reducing visibility to zero. When wet, it can make paved surfaces slippery and impassable. Fine ash is abrasive, damaging surfaces and moving parts of machinery, vehicles, and aircraft. Life-threatening and costly damage can occur to aircraft that fly through fine ash clouds. Newly fallen volcanic ash may result in short-term physical and chemical changes in water quality. Close to the volcano, heavy ash fall may cause roofs to collapse, waste water systems to clog, and power systems to shut down. In agricultural areas, fine ash can damage crops, and sicken livestock. Re-suspension of ash by human activity and wind cause continuing disruption to daily life.
<b>Ballistics</b>	Ballistic ejection of coarse, hot fragments of lava from the volcanic vent. Impact zones are usually constrained to the flanks of the volcano. Fragments are usually softball size or smaller.	The impact of coarse air fall is limited to the immediate area of the volcanic vent. Structures may be damaged by accumulation of falling lava fragments or burnt by their high heat. Wildfires may be ignited.
<b>Floods</b>	Sudden melting of snow/ice by volcanic heat, and/or diversion of water by blocked drainages or breached embankments.	Impacts are similar those of non-volcanic floods, but the onset is usually sudden.

Source: Cal OES Earthquake, Tsunami, and Volcano

### Past Eruptions and Present Day Volcanic Unrest

The most recent eruption in California occurred at Lassen Peak in Lassen Volcanic National Park about 100 years ago, from 1914 to 1917. Geophysical and geochemical monitoring conducted by the USGS CalVO reveals the presence of magma (molten rock) beneath seven of the eight California volcanoes ranked as Moderate, High, or Very High Threat. Low levels of volcanic seismicity, emissions of noxious volcanic gas, and/or ground deformation characterize the present status of Medicine Lake, Mount Shasta, Lassen Volcanic Center, Clear Lake Volcanic Field, Long Valley Volcanic Region, Coso Volcanic Field, and Salton Buttes.

### Volcanic Activity in California's Past and Future: The Lassen Peak Example

**Volcanic Profile:** Lassen Volcanic Center (LVC) lies in Lassen Volcanic National Park about 55 miles east of the town of Redding. The park draws over 350,000 visitors each year with the spectacular volcanic landscapes created by the hundreds of eruptions occurring over its 825,000-year lifespan.

The last 25,000 years at LVC have been relatively quiet with three notable exceptions: the Chaos Crags eruption (1,100 years ago), the eruption of Cinder Cone (345 years ago), and the Lassen Peak eruption (1914 to 1917). The most recent eruption was confined to sporadic steam blasts until May 1915, when partially molten rock oozing from the Lassen Peak vent began building a precarious lava dome. The dome collapsed on May 19 of that year, sending a hot pyroclastic flow racing down the north flank of the volcano.

#### 1915 Eruption of Lassen Peak as Seen from Red Bluff



*Photo by R.E. Stinson courtesy of the National Park Service*

Three days later, a vertical column of fine ash exploded from the vent reaching altitudes of 30,000 feet. A snapshot of the ash column taken from the town of Red Bluff some 40 miles west of the volcano is shown above (R.E. Stinson, courtesy of the National Park Service). Fine ash particles from the top of the column drifted downwind 200 miles to the east, as far as Winnemucca, Nevada. On both days, melting snow fueled lahars, flooding drainages 20 to 30 miles away.

**Volcano Monitoring:** Geophysical and geochemical studies show that a residual reservoir of partially crystallized magma is slowly cooling under the Lassen Volcanic Center. Heat from this reservoir emanates upward, driving a geothermal system at shallow depths, and, at the surface, the hot springs, steam vents, and boiling mud pots that attract park visitors.

Although the annual probability of renewed volcanism is small presently (about 1 chance in 7,150), LVC is still “alive” and future eruptions are inevitable. For this reason, a United States Geological Survey California Volcano Observatory (USGS CalVO) monitoring network of six seismometers and seven continuously recording Global

Positioning System (GPS) receivers is located within 10 miles of Lassen Peak. These sensors continuously transmit earthquake and ground deformation data to observatory scientists, and periodic geochemical and thermal surveys of volcanic gas vents and hot springs are ongoing.

Combined, earthquake, ground deformation, and gas sensors provide the data scientists need to recognize escalating unrest at LVC in time to warn civil authorities and the public before an eruption occurs. See <https://pubs.usgs.gov/sir/2012/5176/a/index.html>.

Future eruptions in California are inevitable, but fortunately, eruptions, unlike other natural hazards such as earthquakes or wildfires, are usually preceded by weeks to months of volcanic unrest manifesting as ground deformation, earthquakes, and/or gas emissions. By monitoring escalating unrest over days, weeks, or months, scientists can produce timely warnings of the impending hazards. Eruptions and continuing volcanic unrest can last longer than other types of natural disaster events taxing emergency response and recovery efforts.

**Chart 6.B: Schematic Comparison of Natural Hazard Timelines**

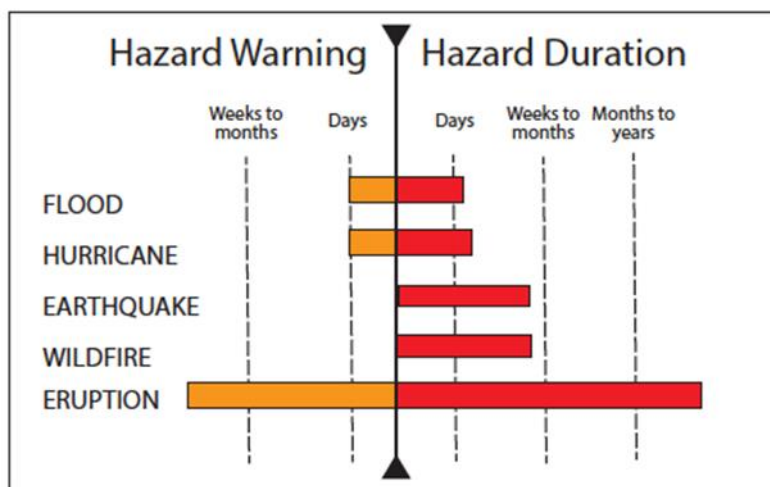


Chart 6.B compares the warning time and duration of various types of natural disasters. Volcanic eruptions are unique in having several days to months of precursory activity, but once initiated, the eruptive activity can persist months, even years before the all clear can be sounded.

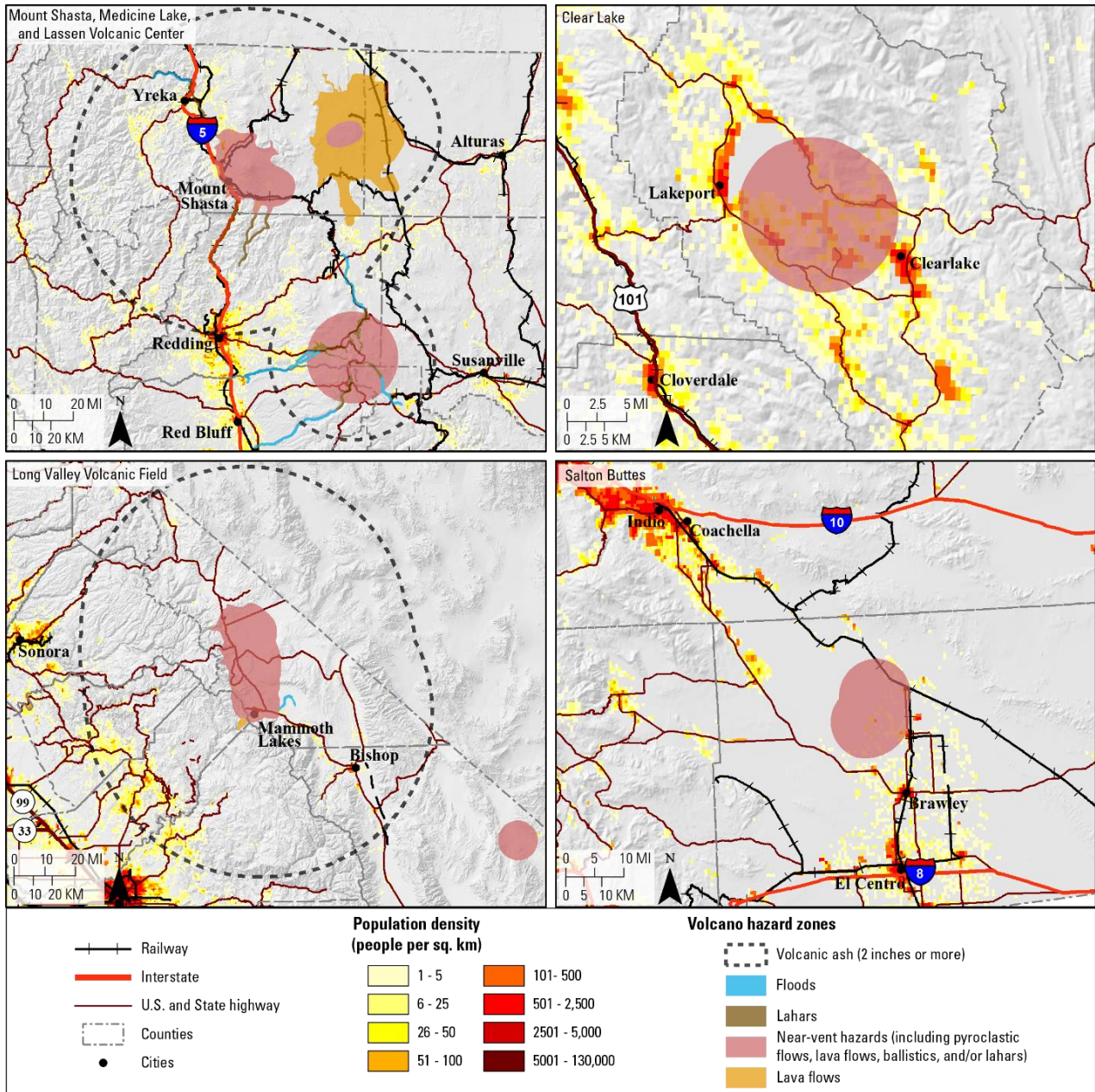
### 6.3.2 ASSESSMENT OF VOLCANO VULNERABILITY AND POTENTIAL LOSSES

#### Volcanic Hazard Zone Mapping

Geologists produce volcanic hazard zone maps to convey the types of hazards that may occur during a future eruption and to constrain the nature and area of impact. The type and severity of adverse impact depend on the eruption style (effusive or explosive), the volume of lava erupted, the location of the eruptive vent, the eruption duration, and local topography and hydrology.

Volcanic hazard zone maps are dynamic—as geologic research progresses, maps of vulnerable areas are updated and new maps are created. The USGS CalVO has published volcanic hazard zone maps for some, but not all, of California’s Moderate, High, and Very High Threat volcanoes. Map 6.DD shows a simplified compilation of California’s volcanic hazard zones. Significant field research is needed to augment hazard zone maps that are incomplete (Clear Lake Volcanic Field, Ubehebe Craters, and Salton Buttes) or non-existent (Coso Volcanic Field).

Map 6.DD: California Volcano Hazard Zones



Source: U.S. Geological Survey

Map 6.DD shows simplified hazard zones for California’s most threatening volcanoes. The map is modified from the USGS reports available on the web at <https://pubs.usgs.gov/bul/1847/>, <https://pubs.usgs.gov/sir/2012/5176/a/index.html>, and [https://pubs.usgs.gov/sir/2007/5174/a/sir2007-5174a\\_text.pdf](https://pubs.usgs.gov/sir/2007/5174/a/sir2007-5174a_text.pdf)

Map 6.EE shows state and county jurisdictions likely to be directly affected by a future eruption in California. The current zonation maps enclose 25,288 square miles, encompassing parts of 17 counties, all Cal OES Administrative Regions, and all but one of the State Mutual Aid Regions. About 62 percent of the land within hazard zones is privately owned; 36 percent is public land managed by the federal government; and state, city, tribal, and special districts collectively comprise 2 percent of the total.

**Map 6.EE: Counties, Cal OES Administrative Regions, and Mutual Aid Administrative Regions Encompassed within Volcano Hazard Zones**



Source: U.S. Geological Survey

Table 6.M shows a partial listing of vulnerable populations and Table 6.N shows a partial list of lifelines located within some of the volcanic hazard zones.

**Table 6.M: Jurisdictions, Populations in Volcano Hazard Zones**

Volcano	Counties within Hazard Zone	Cal OES Administrative Region	State Mutual Aid Region	Federal/State Management <sup>1</sup>	Daily Population <sup>2</sup>
Medicine Lake	Modoc, Siskiyou, Shasta	Inland	III	USFS; NPS; BLM; USFW; CDPR	1,000
Mount Shasta	Siskiyou, Shasta	Inland	III	USFS; NPS; BLM; CDPR	100,000
Lassen Volcanic Center	Shasta, Lassen, Tehama, Plumas	Inland	III	USFS; NPS; BLM; CDPR	10,000
Clear Lake Volcanic Field	Lake	Coastal	II	CDPR	18,000
Long Valley Volcanic Region	Mono, Inyo, Tuolumne, Mariposa, Madera, Fresno	Inland	IV, V, VI	USFS; NPS; CDPR	63,000
Ubehebe Craters	Inyo	Inland	VI	NPS	0
Coso Volcanic Zone	Inyo	Inland	VI	DOD; BLM	not available
Salton Buttes	Imperial	Southern	VI	BLM; USFW	2,000

Source: California Governor’s Office of Emergency Services (Cal OES), Earthquake, Tsunami, and Volcano Program

<sup>1</sup>Abbreviations: NPS National Park Service; USFS United States Forest Service; BLM United States Bureau of Land Management; USFW United States Fish and Wildlife Service; DOD United States Department of Defense; CDPR California Department of Parks and Recreation.

<sup>2</sup>Daily population from ORNL LandScan™ 2012 model rounded to the nearest 1,000. These data do not include intermittent populations visiting recreational areas within, or partially within, volcanic hazard zones, which include nine state parks, eight national forests, and six national parks. Usage statistics suggest over 20 million people visit these sites annually.

**Table 6.N: Lifelines Located in Volcano Hazard Zones**

Lifeline Utilities (water, power, transportation)
<ul style="list-style-type: none"> <li>• Important hydroelectric power plants are located within ash fall hazard zones, including the Shasta Dam and Pit River facilities in Northern California.</li> <li>• High voltage DC and AC transmission lines bringing power to California from hydroelectric plants in the Pacific Northwest pass through volcanic hazard zones.</li> <li>• California’s geothermal power plants are within or adjacent to volcano hazard zones, including the Geysers, Casa Diablo, Coso, and Salton Sea facilities.</li> <li>• Interstate natural gas pipelines entering the state from the Malin Hub (OR) pass through the overlapping Shasta-Lassen-Medicine Lake hazard zones. This system supports residential customers and businesses from north of Redding to south of Bakersfield.</li> <li>• Three key water projects in the State, the Central Valley Project, San Francisco’s Hetch Hetchy Project, and the Los Angeles Aqueduct, have substantial assets in volcanic hazard zones.</li> <li>• Over 2,500 miles of Interstate and state roads are in volcanic hazard zones, including a stretch of Interstate 5 in northern California over which tens of millions of vehicles travel annually.</li> </ul>

Source: California Governor’s Office of Emergency Services (Cal OES), Earthquake, Tsunami, and Volcano Program

## Assessment of Local Vulnerability and Potential Losses

Information related to community vulnerability and loss assessments may be found in Local Hazard Mitigation Plans.

### 6.3.3 CURRENT VOLCANO HAZARD MITIGATION EFFORTS

#### Overview

Robust volcano monitoring networks and effective warning schemes are essential to saving lives and reducing property losses. The USGS California Volcano Observatory headquartered in Menlo Park, California obtains and interprets data from real-time monitoring sensors installed on California’s Very High, High, and Moderate Threat volcanoes, although network coverage is minimal at some locations. See monitoring capabilities and data at: <http://volcanoes.usgs.gov/observatories/calvo/>.

The sensor networks automatically and continually relay data to CalVO scientists for interpretation. Information is communicated to emergency response agencies and the public using alert level schemes for ground-based and airborne hazards (Tables 6.O and 6.P). A no-cost, email-based Volcano Notification Service (VNS) is available to agencies, businesses, and the public by registering online at: <http://volcanoes.usgs.gov/vns/help.php>.

VNS sends volcano status updates to subscribers, including notification of alert level changes, details of volcanic unrest, and eruption information. Figure 6.D illustrates the flow of information from monitoring networks to civil authorities and other stakeholders.

**Table 6.O: Ground-Based Volcanic Hazard Alert Levels**

<b>Volcano Alert Levels Used by USGS Volcano Observatories</b>	
<small>Alert Levels are intended to inform people on the ground about a volcano’s status and are issued in conjunction with the Aviation Color Code. Notifications are issued for both increasing and decreasing volcanic activity and are accompanied by text with details (as known) about the nature of the unrest or eruption and about potential or current hazards and likely outcomes.</small>	
<b>Term</b>	<b>Description</b>
<b>NORMAL</b>	Volcano is in typical background, noneruptive state <i>or, after a change from a higher level,</i> volcanic activity has ceased and volcano has returned to noneruptive background state.
<b>ADVISORY</b>	Volcano is exhibiting signs of elevated unrest above known background level <i>or, after a change from a higher level,</i> volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
<b>WATCH</b>	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, <b>OR</b> eruption is underway but poses limited hazards.
<b>WARNING</b>	Hazardous eruption is imminent, underway, or suspected.

**Table 6.P: Airborne Volcanic Hazards Alert Levels**

<b>Aviation Color Code Used by USGS Volcano Observatories</b>	
Color codes, which are in accordance with recommended International Civil Aviation Organization (ICAO) procedures, are intended to inform the aviation sector about a volcano's status and are issued in conjunction with an Alert Level. Notifications are issued for both increasing and decreasing volcanic activity and are accompanied by text with details (as known) about the nature of the unrest or eruption, especially in regard to ash-plume information and likely outcomes.	
<b>Color</b>	<b>Description</b>
<b>GREEN</b>	Volcano is in typical background, noneruptive state or, after a change from a higher level, volcanic activity has ceased and volcano has returned to noneruptive background state.
<b>YELLOW</b>	Volcano is exhibiting signs of elevated unrest above known background level or, after a change from a higher level, volcanic activity has decreased significantly but continues to be closely monitored for possible renewed increase.
<b>ORANGE</b>	Volcano is exhibiting heightened or escalating unrest with increased potential of eruption, timeframe uncertain, <b>OR</b> eruption is underway with no or minor volcanic-ash emissions [ash-plume height specified, if possible].
<b>RED</b>	Eruption is imminent with significant emission of volcanic ash into the atmosphere likely <b>OR</b> eruption is underway or suspected with significant emission of volcanic ash into the atmosphere [ash-plume height specified, if possible].

### Volcano Hazard Vulnerability Assessment

Effective volcano monitoring, alerting, and pre-disaster planning are essential to reducing loss of life and property, but long-term mitigation efforts require knowledge of the proximity of people and assets to hazardous volcanoes. In California, identifying what and who is in harm’s way is the critical next step in mitigation enhancement.

In cooperation with the California Geological Survey (CGS), and support from State of California Governor’s Office of Emergency Services (Cal OES), the U.S. Geological Survey (USGS) California Volcano Observatory is working to provide broad perspective on the state’s exposure and vulnerability to volcanic hazards by integrating existing volcanic hazard zones with geospatial data on at-risk populations, infrastructure, and resources.

The analysis, which is under review by state and federal stakeholders in 2018, focuses on five themes: 1) land cover, ownership, and jurisdictions; 2) ambient and intermittent populations; 3) lifeline utilities; 4) agriculture and forestry; and 5) community services and emergency facilities. This statewide information will form the basic framework needed to lead site- and vector-specific mitigation efforts. The report is to be published at the end of 2018 and will be available on the USGS and CGS websites.

Figure 6.D: Hazard Information Flow from USGS Monitoring Networks to Civil Authorities and Stakeholders

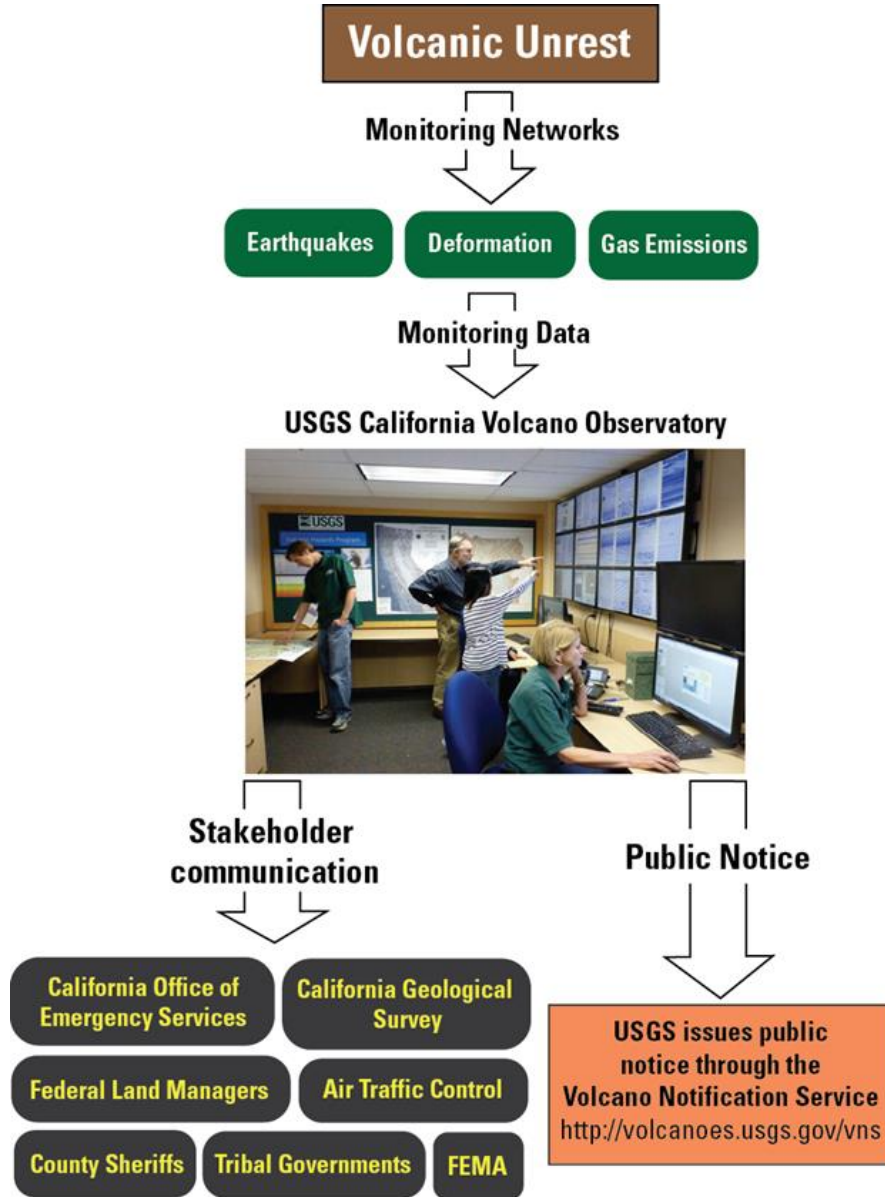


Figure 6.D shows how information flows from monitoring networks to observatory staff, where it is interpreted for stakeholder and public mitigation, planning, and response activities.

### 6.3.4 ADDITIONAL VOLCANO HAZARD MITIGATION OPPORTUNITIES

Providing a statewide analysis of California’s exposure to volcanic hazards through the state volcano vulnerability assessment due to be completed in 2018 will prompt follow-up site- and sector-specific vulnerability analyses that will lead to greater awareness of the threat and improved hazard mitigation and response protocols.